THE INDUSTRIAL CONSEQUENCES OF DEFICIENCIES OF COLOUR VISION.

A Thesis Submitted By

JANET VOKE

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Department of Ophthalmic Optics
and Visual Science

The City University, London

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ABSTRACT

A number of industries involved with coloured products were surveyed to assess the role of visual colour judgement in the processes and determine the industrial handicap of defective colour vision. The colour vision testing policies of the individual companies were investigated and an attempt was made to discover the industrial mistakes which could be attributed to defective colour vision. Visits were made to selected industries to supplement information obtained from a postal survey. Discussions with Employment Medical Advisers and Industrial Medical Officers proved to be valuable. A field trial to determine the performance of paper colour matchers at standard colour vision tests was undertaken. A number of industrial jobs involving colour judgement were simulated in the laboratory. One hundred colour defective observers and a group of colour normals took part in the tasks, and an analysis of their performance is presented. In particular, comparisons are drawn between performance at these tasks and scores on standard colour vision tests. An enquiry into the colour vision tests used in school medical examinations was made and the career guidance given to colour defective children throughout England and Wales was studied. A list of occupations, jobs and careers which are likely to cause difficulty to the colour defective are presented. Finally recommendations concerning colour vision testing in industry are given.

SECTION I

1.1 AIMS OF RESEARCH

The aims of this research are:

1. To survey those industries involved with colour with a view to:

   (i) evaluating the role of visual colour judgement in the colour processes, as compared to instrumental control, and hence determining how handicapped a colour defective observer would be in this work.

   (ii) investigating the extent to which colour vision testing is carried out among those employees required to exercise colour judgement and the testing methods used. In particular to see if there is any change in the extent and types of tests used since the 1946 study, since it would be expected that improvement would have taken place.

   (iii) discovering specific errors made in industry which could be attributed to defective colour vision.

This aspect was covered by a questionaire sent to almost five hundred representatives of colour industries (approximately three hundred and fifty were returned), followed up by personal visits to fifty selected companies and research associations. The results are presented in Section 3.

2. To determine the ability of colour defective observers at selected industrial colour jobs by simulating these situations in the laboratory. The results are presented in Section 4.

3. To make firm recommendations about the most suitable testing methods, to investigate the industrial consequences of different degrees of defect; arising out of this to improve guidance for career purposes. The recommendations are presented in Sections 6 and 7 . Each of these points was seen to be important.

1.2 INTRODUCTION

Colour has played a major role in certain occupations and professions for centuries. Long before industry became organised on the scale we see today, the activities of hunting and gathering food must have been difficult for those with defective colour vision. The famous coloured mosaics of the Romans and the illuminated manuscripts of the Middle Ages are examples of pre-industrial products which were acceptable only with the correct choice of colours.

The dyeing of cloth and yarn must be one of the early established c lour industries in England. The need for colour control and uniformity was recognised. TANN (1967) noted that Gloucestershire cloth was inspected on arrival in London in the late sixteenth century and that clothiers were fined if the goods did not conform to the statutory length and breadth, or if the colour was faulty. Certain areas of the West Country were noted for the colour of their cloth eg. the red cloth of Stroud and the blue of Uley and Cirencester. Several historical cases are on record of colour defective individuals who had difficulty in identifying the colour of textiles. JEFFRIES (1883) quotes the case of a minister of the Society of Friends (Quakers) who selected the forbidden scarlet cloth as material for a new coat. The problem was also experienced by the protanope DALTON (1798), also a Quaker, who noted "Woolen yarn dyed crimson or dark blue is the same to me, and green woolen cloth, such as is used to cover tables, appears to me a dull dark, brownish-red colour; it resembles a red soil just turned up by the plough. When this kind of cloth looses its colour and turns yellow, as other people say, then it appears to me a pleasant green."

There is no doubt that industry has felt the effect of colour vision deficiencies for many years. JEFFRIES (1883) reports numerous cases of individuals who were frequently in doubt about colours in their work. These instances exemplify the diversity of occupations and industries where colour mistakes cause inefficiency, financial losses and often personal embarressment.

"A tradesman reported his boy assistant as offering pink and pale green paper as good matches; he frequently caused his master trouble by binding books in the wrong colours.

An architect reported having to release a pupil apprentice in consequence of finding him copying a brown house in blueish-green paint, the sky rose-colour and roses blue.

A manufacturer reported that one of his weavers had to have the red and green threads selected by another as he could not distinguish them.

A Post-Office clerk in Prussia was found to be constantly in trouble with the stamps. The accounts would come out wrong - sometimes there was not enough money for stamps sold, on other occasions there was too much. This made dishonesty on his part less likely but it was incomprehensible how he would make the accounts so entangled. At length it was discovered that he was colour blind and could not distinguish red from green stamps. (Reported in the Boston Medical and Surgical Journal, December 27th, 1877).

A farmer who could not tell red apples from the surrounding green leaves except by their shape.

A physician who wrote of his difficulty in identifying the colour of throats, ulcers, gangrene and some sores.

A young man whose profession required him to deal much in coloured tissues, found that the only way of telling the difference between scarlet and green or blue and crimson was to take them into a room lighted with gas or candle, when the distinction which was invisible by daylight became apparent."

JEFFRIES (1883) noted that

> "Volumes might be written on this subject if all the different instances of all the peculiarities presented with colour-blindness and all the embarrassment to which they gave rise, were cited."

Isolated examples also appear in the literature. Harris, the shoemaker, from Maryport, Cumberland, is described by HUDDART (1777 and is often considered to be one of the earliest recorded persons with defective colour vision. In a letter from J. Scott to the Rev. Whisson of Trinity College, Cambridge, concerning "An account of a remarkable imperfection of sight," WHISSON (1778), Scott describes his difficulty with colours:-

> "My business was behind a counter many years, where I had to do with a variety of colours. I often, when alone, met with

a difficulty; but I commonly had a servant in the way to attend me, who made up my deficiency. I have now been seven years from trade."

Since the days of these reports manufactured goods have become more colourful, with a wider range of colours being available due to improved techniques and availability of raw materials. Industrial competition requires the colour tolerances of consumer goods to be small.

The customer is more aware and discerning and his greater prosperity enables him to demand smaller tolerances. Advertising too uses colour more and more, and a strong emphasis is placed upon appealing choice of colour for packaging. Very high standards of colour reproduction are demanded for advertisements. The Representation of Goods Act requires careful colour control and faithful reproduction. Recently care has been taken to ensure good colour rendering and the colour rendering index of illuminants is often a major consideration.

Despite the development of colorimeters, spectrophotometers and computers,the human visual system continues to play a vital role in colour assessment in industry. Colour coding is used increasingly to facilitate identification in the industrial context. National and international organisations have been set up to co-ordinate colour activities and make recommendations which minimise confusion and are invaluable to industry. The British Standards Institution is one such recommending body in Britain. The British Colour Council, set up in 1930, included the establishment of visual standards on colour. The Inter-Society Colour Council (I.S.C.C.) co-ordinates the activities of different colour orientated societies e.g. the Colour Group of Great Britain and the Optical Society of America on an international basis. It is active in committee work formulating questions and attempting answers, and regularly publishes recommendation and journals. One of its long-standing projects is the Colour Aptitude test which was designed with industry in mind to assess colour discrimination ability. The Colour Group of Great Britain, which was once part of the Physical Society, was formed in 1940 to provide an opportunity for those engaged in colour work in industry and in training and academic establishments to meet to discuss the Scientific and technical aspects of their work. Today the Group has over three hundred members and a Northern and Sc ttish Section who hold meetings in addition to the monthly Scientific Meetings held in London.

It was the Colour Group who first realised the need for a survey to be made of the importance of defective colour vision in industry. The suggestion to form a committee to consider this subject was made at a meeting of the Group in December 1941. The Committee appointed by the Group published its findings in 1946. This document has proved to be most valuable and it remains the only comprehensive survey of the role and importance of visual colour judgement in industry and the attitude of industry, towards colour vision testing and defective colour vision.

However, in thirty years considerable changes have occurred in the fields covered by the report and new areas and ideas have come to be of importance. There is a greater general awareness of the importance of selecting only those with good colour vision for jobs specifically concerned with colour, as the widespread testing of school children for colour anomalies indicates. New industries have developed and new colour vision tests have been designed. Colour coding has assumed greater importance in all sections of industry, commerce and business. No study on colour vision in industry, of any significance has been published since the 1946 report and there has never been a systematic effort to simulate industrial colour jobs in the laboratory. The research findings presented here are intended to make good this need.

SECTION II

Previous Work

2.1

One of the earliest studies in which the possible occupational handicap of defective colour vision was considered was an American survey by MILES AND CRAIG (1931). They tested the colour vision of three hundred and seventy-five salesmen who were selling coloured goods - carpets, mens' clothing, furniture, and textiles. Twenty-seven employees (7.2%) were found to have abnormal colour vision on the Ishihara Test - a figure which is comparable to the expected percentage for a random Caucasion population, and suggests that no self-selection by occupation had taken place. Further enquiries were made among the colour defective salesmen concerning the role of colour in their daily work. It was estimated that at least half were in aposition to cause embarrassment to customers or to the company because of their defect. One department, where a colour defective salesman was employed, had an unusually high record of returned goods which were found after purchase to be unsatisfactory. Although not all could be attributed to the defective colour vision of the salesman errors of this nature were reported on occasions. Some of the colour defective salesmen used other clues to locate coloured goods; for instance one man placed certain coloured merchandise on definite shelves so that he knew where to locate them. No instances where defective colour vision was a specific asset or benefit to the salesmen were recorded. The authors strongly recommend the use of the Ishihara Test at the initial interview stage for new employees concerned with coloured goods in shops, and further tests for those who fail.

An interest in the subject of selection of workers for colour jobs arose in Britain about the same time. In 1926 the National Institute of Industrial Psychology was approached by a firm of colour printers who required a test to enable them to select for responsible positions employees who were least likely to make errors in the matching of colours. This request initiated a full-scale research project which extended over seven years and is described in detail by PEARCE (1934). Pearce studied a report of the Optical Society of America (1931) which contained a series of papers on industrial colour standards and the relative merits of photo-electric methods in colorimetry, as compared with visual evaluation. He was convinced that subjective judgement was superior to objective methods for colour inspection and assessment of colour tolerances, and set out to devise a test which would detect variations in colour matching ability among colour normal observers. The purpose was not to detect or classify those with anomalies of colour vision - only the variations in ability in colour normals. Two tests were developed - a grading test and a matching test which were similar in design and used coloured glasses of different saturations. Extensive trials were carried out with both tests using experienced colour matchers from a variety of colour industries, as well as naive observers, before a final design was adopted. For the former group there was a good correlation between ability at the test and efficiency at industrial colour work. Pearce considered that the use of the test in selection procedure for operatives involved in colour work would raise the standard of work and help to improve the speed of operation. It is unfortunate that the test did not seem to be used widely after its development.

Another rather unconventional test used for industrial screening is described by TIFFIN AND KUKN (1942). These authors surveyed the colour vision of seven thousand industrial employees working in a sheet and tin mill. They separated the industrial employees into groups - different age groups and merit groups - to see if defective colour vision was in any way associated with poor or good job performance. An analysis was made of the percentage of employees engaged in different jobs who passed the colour vision test. The results showed that at every age level the group who had been rated high in job performance contained a larger proportion of employees who passed the colour vision test than those classified as poor at their work. Foremen and clerks seemed to have a particularly high pass rate. With increasing age a smaller percentage passed the colour vision test. The failure rates were much higher than is usually associated with Caucasion population samples. Twenty-six percent of industrial employees aged between twenty and twenty-five failed the test and sixty-eight percent above the age of fifty-five failed. It appears that the unusually high failure rate results from the test used. It is described as a simple four item red-green colour discrimination test. It was designed by Mason and is described by him as "A kodachrome transparency of the Ishihara Test which is placed in a Stereogram" MASON (1944). The authors accept that the test is not ideal for industrial purposes but maintain that a need exists for a fine test of colour discrimination which can be used in industry. They reported that only five percent of jobs within the tin industry investigated required good colour discrimination and identified certain industrial jobs dependent on good colour vision which had not been noted as such before. It is unfortunate that few details of this aspect are given in the account.

A paper entitled, "Colour blindness and its importance in relation to industry," which was read to the Colour Group of Great Britain by

Dr. F. Pitt, during the war years of 1941, proved to be of considerable importance. A lively discussion followed the presentation and the paper was later published in the Proceedings of the Physical Society Pitt (1942). General problems were mostly considered. Dr. Pitt quoted many examples of industrial areas where colour defective individuals would be handicapped or even in positions of danger. The need for pre-employment testing of colour vision was stressed, and the desirability of testing during the school years was raised. It was this aspect which occupied much of the discussion time. A member of the audience, who contributed to this discussion, a Dr. Shaxby, suggested that a special sub-committee of the Colour Group should be f rmed to obtain information from industries involved with col ured products " f the techniques and processes in which colour deficiency is a bar, and particularly those in which is caused slowness or uncertainty". As a result of this suggestion, a committee was appointed in February 1942 by the Physical Society Colour Group Committee with the f llowing Terms of Reference:

> "To obtain as complete information as possible as to the techniques and processes in which deficiencies of colour vision are a handicap, to report on existing methods of testing such deficiencies in Industry and in schools and to make recommendati ns regarding the improvement and co-ordination of these tests.

The committee consisted of the following members:

Chairman: J. H. Shaxby D.Sc. Physiology Institute, University College Cardiff.

G. H. Griles F.B.O.A. (Hons) F.S.M.C. British Optical Association.

G. E. Graves-Peirce. M.B. F.R.C.S. Medical Officer, LMS Railwasy

F.H.G. Pitt PhD A.R.C.S. Kodak Ltd.

J.W. Strange PhD A.R.C.S. Thorn Electrical Ltd.

W. H. Tylor D.Sc PhD Crystallographic Laboratory Cambridge.

W. D. Wright, D.Sc. PhD Imperial College London University

Hon. Sec: H. M. Cartwright F.R.P.S. (Lcc School of Photo-engraving)

The Committee held twenty meetings and as a result of the information obtained and discussions held, a report was produced in the form of a booklet entiled "Report on Defective Colour Vision in Industry" (1946)

The Committee considered "the disabilities or difficulties to which defective colour vision might give rise in industry and the tests which would best assure the assignment of employees to duties within their powers of colour discrimination."

They selected for detailed investigation industries concerned primarily with colour, and tried to obtain information of the class of workers requiring good colour vision, Professions, police railways and shipping.

The study included a brief consideration of the colour vision requirements in the services. A section was also devoted to the tests of colour visi n at a pre-vocational level, including testing in schools, and recommendations on this aspect were made.

The inf rmation for the study was obtained by contacting over a hundred individuals, companies and Research Associations a complete list of which appears in the Report. The professions and industries studied are given below and a brief report on each was made:

- Agriculture and Horticulture
- Building and Allied Trades
- Biology
- Catering
- Chemistry
- Dyestuffs/Drapery
- Electrical & Mechanical Eng.
- Illuminating Engineering
- Medicine
- Geology and Mining
- Oil Industry
- Paint Industry
- Paper Industry
- Photography
- Physics
- Printing
- Inks
- Pottery.

An effort was made to analyse the extent to which defective colour vision would be a handicap to individuals working in industries concerned with colour. It was hoped to discover the number of colour defectives who were actually working in critical colour situations, but this proved to be difficult. A summary of the findings related to specific industries is given in section .3. of this study.

The investigators found little uniformity in the colour vision testing methods used in industry, either in the nature of the tests used or in the stringency of the examination. The majority of companies, except a few where critical colour processes were involved, did not consider colour vision testing to be very important.

The ease of transfer f persons who were found to be unsuitable for a particular job, to more suitable occupations, was frequently given as a reason. The Ishihera test was most commonly encountered.Most companies seemed satisfied with this method although representatives of both dyeing and printing ink companies felt that there was not much correlation between performance at the test and practical colour ability.

Companies within the photographic industry, printing inks, printing and textile industries used the Ishihera test, but testing was usually restricted to a few individuals in key colour positions; for instance, in the textile industry a colour vision test was only given to individuals in the weaving and dyeing divisions. Trade tests were common in the electrical industry and on a limited scale in the printing ink industry it was found that little care was taken to ensure that the conditions of the specimens used for trade tests (e.g. coloured wires, resistors and capacitors) were similar to those encountered in practice (e.g. soiled specimens). The Committee recommended that where trade tests are given care should be taken to use old specimens.

A survey of the colour discrimination of textile workers carried out by RICHTER (1954) is one of few systematic industrial investigations to use a battery of colour vision tests. In this study a total of one thousand three hundred male and female employees of textile or dyeing establishments and textile colleges were examined in three different areas of Germany. The tests used were chosen with the anomalous trichromat in mind, since it was thought that few dichromats would be encountered in the textile industry. The results, however, revealed a proportion of colour defectives almost identical to an average population sample, indicating virtually no automatic or self-selection by occupation. Richter used a selection of pseudo-isochromatic plates (five different kinds) illuminated in daylight, and the nagel anomaloscope. Subjects were required to pass both the PIC tests and the anomaloscope. Some factories sent all their colour workers, other sent only those in important positions, in a few cases suspected colour defectives were examined.

Customers and those with whom factory personnel had had differences of opinion were also seen. It was thought that some factories deliberately held back known colour defectives or suspect observers for fear that their customers would find out. In fact each company was given the results confidentially and it was left to their discretion to make any changes in staff placement. A total of eighty eight of those examined were classified as colour defectives. Of these, eleven were protanopes, eight protanomalous, nine deuteranopes and sixty deuteranomalous. The occupations of those found to have defective colour vision were investigated. These are given below:

<u>Protanopes</u>

factory hand .	manager
works assistant	bleacher
dyer	technician
textile salesman	student studying dyeing.
apprentice lab-technician.	
person who prepared cloth to be dyed.	
person who prepared cloth to be printed.	

Deuteranopes

Textile chemist
Dye Chemist
Varnisher
Apprentice film printer
Person who prepares yarn to be woven
Person who weighs pigments.
printer
Packer
Textile salesman

Protonamalous

2 Dyers
2 Apprentice furnishers
2 Apprentice pattern designers.
Dye forman
Dye foreman's assistants

Deuteran mel us

6 Dyer apprentices
6 Textile Engineers
6 Textile Chemists
5 Dyers
2 Buyers
2 Pattern Designers
2 Printing Foreman
2 Painters
5 salesmen of textiles
3 Drivers
3 Dyeing Students
2 Factory Hands
2 Dye Foremen
2 Factory Engineers
2 Factory Foremen
2 Printers
2 People who prepare material for dyeing
2 Directors of printing colleges
Section group leader
Head of Dye Section
Head of Bleaching Section
Head of General Works.

In one case not only the dyer but also his assistant and the quality control supervisor all had deuteranomalous vision.

RICHTER (1964) strongly advised that colour vision testing of personnel concerned with colour in industry vision tests should take place at the pre-employment stage. He considers that a large number of the colour defectives found in the establishments concerned were unsuited to their present employment.

He considers that colour defectives should only be placed on work which only involves single colours, and recommends that they should not be expected to make judgements where critical tolerances are involved.

There are few other direct studies of major importance, concerned with the industrial handicap of defective colour vision, but a number of authors have made useful comments on the subject.

PEARCE (1934) and MACGILLIVRAY (1947) emphasised the part played by the partially col ur blind in slowing down industry. PEARCE (1934) also stresses the financial consequences of industrial errors. CAVANAGH (1955 menti ns the possible danger to personnel when those who are unaware f their col ur anomaly are put in positions of responsibility in industry. The problems of the colour defective working in banks where col ured slips are used is mentioned by ICHIKAWA et al (1969) and CAVANAGH 1955 found that dichromats are incapable of using such colour codes. NORMAN (1948 n tes that there are no statistics available of accidents in which the defective colour vision of an employee may have been responsible.

DREYER (1969 considers that in vocations outside the traffic section one "cann t afford" to reject eight per cent of all applicants. Understandably the suitability of colour vision tests for industrial purposes has received most attention. DREYER (1969) attempted to find a test best suited to assess the occupational fitness of a colour defective and concluded that the DIS test was most suitable. The reader is referred to Section 2.3 for further comments on this aspect.

The industrial consequence of acquired defects of colour vision have received rather little attention in the literature. The problems associated with tobacco amblyopia were frequently discussed in connection with railway personnel, particularly in the American Medical literature at the end of the last century. MACGILLIVRAY (1947) cited the example of a postman who had difficulty in distinguishing between green ½d stamps and red 1d stamps, both of which he called greenish-brown, because of tobacco amblyopia.

Few studies have been made to investigate the ability of colour defective observers at industrial colour jobs. FETTER (1963) compared the accuracy with which colour normal observers and ten colour defectives performed colorimetric laboratory tests covering a wide range of colours. The tests involved, checks for protein, pH, sugar, glucose ketone bodies etc. or urine samples. Colour defectives obtained excellent results in six of the tests used and showed ability to evaluate an increase in colour intensity as well as differences in colour. WARBURTON (1954) mentions brief findings with three colour defective observers at matching textiles.

2.2 Colour Coding

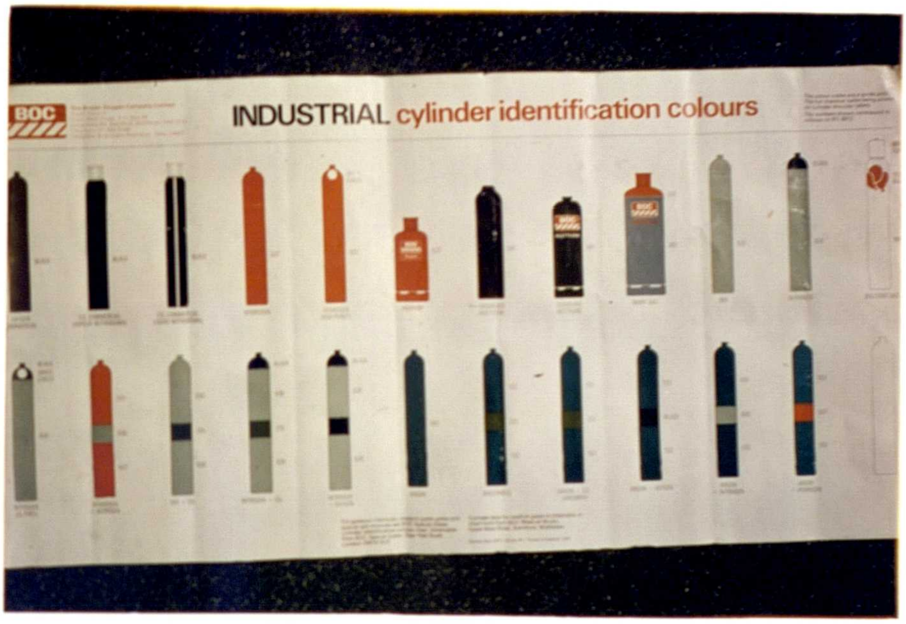
Colour is used extensively in industry and commerce, and in navigation and military situations to code information. In many cases the correct identification of a colour code is essential for safe and efficient work. As RIDDELL (1948) points out colours have been used for this purpose for many centuries - firstly in the form of flags for identification purposes and later to convey orders. Knights depicted on the Bayeaux Tapistry had individual coloured banners. Over the years certain colour associations have developed; these are summarised below:

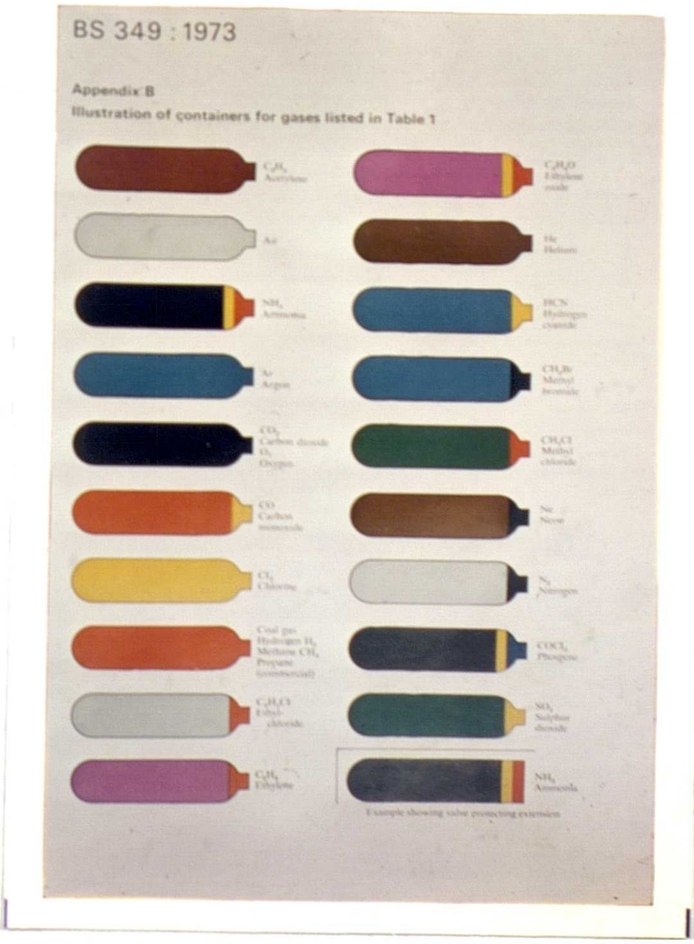
Colour	Meaning
Red	Danger/mutiny/Revolution
Black	Piracy/Execution
Yellow	Plague/infection
White	Surrender/truce

Based on these common meanings the safety colour code issued by the British Colour Council advocates the following uses:

Colour	Meaning
Red	Danger/fire protection
Orange	Attention/possible danger
Yellow	Take care
Blue	calm caution
Green	safety
White	Cleanliness

COLOUR CODING





identification of pipelines is a typical example - details of which are given below:

Contents	Colour Code
Water	Green
Steam	Silver Grey
Oils (mineral, animal vegetable)	Brown
Combustile liquids Gases in gaseous or liquified condition except air	Yellow/light buff
Acids and alkalis	Violet
Air	Light Blue
Other fluids	Black
Electrical Services	Orange

Table 1 Identification of Pipelines - Colour Code B.S. 1710 (1971)

It is most important that the colour identification bands are painted at intevals on the piping, particularly at the source and termination of supply and wherever the pipes pass through walls.

Numerous studies have been carried out on the optimum use of colour in coding systems, JONES (1962), CONOVER et al (1958), SMITH (1962), GREEN AND ANDERSON(1956), SMITH, FARQUHAR AND THOMAS (1965), and REYNO LDS (1972). Research has shown that under optimal viewing conditions between five and twelve colours can be distinguished reliably, and there is evidence that colour is better than shape in tasks which involve locating displayed data CONOVER et al (1958). As many as thirty categories can be identified if three dimensions of colour (hue brightness and saturation) are used BISHOP AND CRODE (1961). GREEN AND ANDERSON (1956) found that when the observers knew the colour of the target the search time is approximately proportional to the number of symbols of the target colour. They also found that the search times are slightly longer for multicoloured displays than for comparable single-coloured displays. SMITH (1962) attempted to confirm these results and found that neither the target colour used, nor the display background had any statistically significant effect. Furthermore he found that for multicoloured displays, when the colour of the target was known in advance, the search times were considerably shorter than when the target colour was unknown. Also when the colour of the target was unknown the search times for multicoloured displays were not significantly different than those for single-coloured displays. REYNOLDS (1972) carried out experiments to determine the most effective colours for stimulus lights as measured by the speed of detection and the accuracy of identification. He found the order to be (fastest to slowest) red, green, yellow, white. For errors in colour naming (least to most) the order was green, red, white, yellow. If the signal to background contrast is low it was shown that there was a marked advantage in using a red signal with green, yellow, white following in that order. Orange is known to be seen best at greatest distances and care must be taken to avoid colours which will be confused by colour normal observers when the angle subtended is 20 minutes of arc or less, due to small field tritanopia.

The special difficulty that the colour defective observer experiences with colour codes has not been forgotten. PITT (1942) mentions the problem and hopes that "one day the various responsible authorities will cease to colour code in the so-called confusion colours". WRIGHT (1953) feels that where possible colour codes should be ancilliary to pattern codes and the colours chosen should be as saturated as possible. WILSON (1960) describes symbols which have been recommended for use in conjunction with safety colours "for the sake of those with defective colour vision". These are given below:

Yellow	Blue
Orange	Green
Red	White

Attempts have been made to select colours for some codes which will cause the least difficulty to colour defectives. This is particularly important for signal lights which depend entirely on colour recognition without any clue from position or shape or surroundings e.g. railway signals. A NASA Report (GSD-A-096) contains colour code recommendations for pigments and indicator lights, which will be "ideal for colour blind persons". These colours are black, white, yellow, blue. Furthermore efforts have been made to reduce the number of colours for colour-coded signal lights (used on display panels, maintenance equipment and in navigational aids to air, marine and surface vehicles) for colour defectives. These colours are recommended for signals "if colour defective observers are expected to respond correctly" - aviation red, green and blue, and the colours are specified carefully. The American Standards Association has a safety colour code for marking physical hazards and the identification of certain equipment in connection with accident prevention. This code was developed at the National Bureau of standards by Keegan with special regard to anomalous colour vision, CONOVER et al (1958). Strict specifications for the purple and grey limits for "safety red" and the yellow limit for "safety green" are documented. Careful thought was also given to this aspect when B.S. 1376 colours of light signals, was revised. The green signal lights have been chosen to have a blueish-green hue which is more reliably recognised than a yellowish-green by both colour normals and colour defective observers.

COLE (1972) reports American and Australian experimental studies of the ability of colour defective observers to recognise colour codes; dichromats were found to be unable to respond to a three category colour code, although attempts have been made to devise colour codes of three or more categories which the dichromat could appreciate, JUDD (1952), KELLY (1968). COLE (1972) recommends that dichromats should not be employed in operations requiring reliable recognition of colour codes involving three or more categories. He mentions that anomalous trichromats will generally have little difficulty unless the code is complex. TAYLOR (1975) maintains that it is possible to choose at least nine different colours which even the colour defective should not confuse. He believes that this principle might have been adopted when the colour code for medical gas cylinders was chosen, but is unable to confirm this.

There is no doubt that careful control of the luminance value and saturation of colours used in codes makes it possible to use colours which would otherwise be confused by many colour defective observers (see results of the present writer's electrical trial page 212.) Good contrast is also important. It is well-known that the detectability of a symbol or code is increased when the colour and brightness contrast between the object and background are increased. The addition of fluorescent substances has become popular recently to increase brightness and contrast and heighten conspicuity; this move has undoubtedly benefited the colour defective.

2.3 Colour Vision Tests and their suitability for Industrial Purposes

An exhaustive survey of the many tests available for detecting and diagnosing colour vision defects is inappropriate in this study. Although McLAREN (1966) estimates that almost two hundred different methods have been used for detecting defective colour vision, only about thirty tests are commonly encountered. Many excellent review papers have been written on the subject JORDINSON AND MINSHALL (1959), McLAREN (1966), LAKOWSKI (1966 and '69) and VOKE(1973). Furthermore the subject is dealt with fully in a number of recent research theses DAIN (1971) and BIRCH(1973), and books LINSKZ (1964) and KALMUS (1965).

It is very difficult to define normal colour vision, and although defects of colour vision are usually classified into convenient groups, a whole spectrum of anomalies is met in practice, and many do not fall unambiguously into any one class. This is most marked for the severity of defects. Since there is no agreed scale defining the type or severity of a colour vision defect the tests available frequently vary slightly in their diagnosis. This is particularly true for tests which are designed on different principles since each type of test measures a different ability. If the anomaloscope is taken as the definitive diagnostic tool, as most authorities accept, the difference between tests may be interpreted as being due to the inadequacies of the various colour vision tests.

There is at present no ideal colour vision test - one which is suitable for widespread use by a non-specialist and which will give an unequivocal diagnosis. Most authorities favour the use of a battery or selection of tests. A final diagnosis of the type or severity of a colour vision defect is made on the basis of the results obtained with three or four independent tests. MURRAY (1943) considers that no individual should be diagnosed as a colour defective on a single test; he believes that at least three different tests are requisite. MASON (1944) confirms this feeling that "any present single colour vision test is not in itself adequate for testing of colour vision for industrial performance". Colour vision tests can be roughly classified into groups and tests used in the battery should be chosen from the different groups.

1. Confusion or pseudo-isochromatic (PIC) tests

e.g. Ishihara, H.R.R., Dvorine, T.M.C.

These are the cheapest, simplest and quickest tests to use and for these reasons they are the most commonly encountered tests and are frequently used in industry. They consist of patterns of variously coloured dots in which a letter or figure has to be recognised against a background. By a careful choice of colours the figure will be invisible to the colour defective. The Ishihara plates, which first appeared in Japan in 1917, are the most popular, and the most sophisticated of the group. An attempt is made to separate protans from deutans (though no tritan plates are included), but the test is generally accepted to be useful only as a screening test, and is inadequate for qualitative or quantitative diagnosis, HARDY et al (1945), CRONE (1961), COLE (1963). The H.R.R. plates, (named after the inventors Hardy, Rand, and Rittler) were produced by the American Optical Company in 1954 and '57. An attempt is made to grade the severity of the protan, deutan and tritan defects by a variation in the saturation of the symbols on the plates. CRONE (1961) and FARNSWORTH (1957) consider it to be good for the quantitative diagnosis of colour deficiency, but CRONE (1961) found it to be poor at separating colour normals from defectives. SLOAN AND HALBEL (1956) consider that misclassification as a colour defective is more likely with the H.R.R. test than with the Ishihara test. HARDY, RAND AND RITTLER (1945) found their plates to be superior to other tests and best in assessing practical colour ability. LAKOWSKI (1969) concisely summarises the view of most authorities in his statement that "a final diagnosis of the extent of defect based on the misreading of P.I.C. plates alone is always difficult, never certain, and at best only probable." Their value in predicting occupational suitability has been compared by COWAN (1942) to a visual acuitychart containing only 6/6 letters.

2. <u>Sorting or matching tests</u>

e.g. Farnsworth-Munsell 100 Hue Test and D.15 Test.

In these tests the subject arranges small coloured paper samples in order to make a colour sequence. The Farnsworth 100 Hue Test was designed by Farnsworth in the early 1940's. The test consists of four sets of twenty one Munsell colours (aperture 1.25cm) mounted in bakelite caps. All the colours are of equal value (lightness) and chroma (saturation) only the hue varies. The colour difference between colours varies from 0.6 to 5.7 N.B.S. units LAKOWSKI (1966). The test is not suitable as a screening test being too time-consuming for this purpose, and is really a measure of hue discrimination. Although the results frequently give some ambiguity in separating protans from deutans and mild deuteranomalous observers from normals, COLE (1963), the test has considerable potential for use in industrial situations where very critical colour matching is required e.g. dyeing, paint and ink industries, and is used by a number of larger industrial organisations and Research Associations to assess colour matching ability.

The Dichotomous D.15 test described by Farnsworth in 1947, uses fifteen evenly spaced hues from the 100 Hue Test plus a reference colour. DREYER (1969) considers the D.15 test to be the best tool for occupational guidance.

3. <u>Lantern tests</u>

e.g. Edridge-Green lantern, Giles-Archer lantern, and Board of Trade lantern.

These tests are essentially trade tests which test the ability of observers to recognise and identify coloured signal lights of varying sizes. Frequently a neutral filter is provided to reduce the overall illumination and a frosted glass or ribbed filter may be added to simulate fog or rain conditions. The test is favoured by the transport services and the Navy and Air Force.

4. <u>Physical Instruments</u>

e.g. Anomaloscope and Tintometer Lovibond Colour Vision Analyser.

The anomaloscope is generally considered to be the most sophisticated means of detecting and classifying colour anomalies. It is one of the few instruments that can distinguish with certainty between anomalous trichromats and dichromats. CRUZ-COKE (1970), GARNER (1942) and others describe it as "the final arbiter in the subjective diagnosis of colour vision deficiencies". The Nagel instrument permits a mixture of red and green in varying proportions to match a monochromatic yellow. The red/green ratio (called the anomaly quotient) required by the colour defective to match yellow is compared with that of a colour normal. Dichromats accept any red-green mixture including the normal setting. Protanopes and deuteranopes are differentiated by the brightness match with yellow, the protanope setting the red field at a very low intensity to match the yellow. RICHTER (1954) used the anomaloscope in his study of the colour vision of textile workers but the instrument is unfortunately too expensive and time-consuming to use as a screening test in industry.

The Lovibond Colour Vision Analyser described by DAIN (1971) was developed for industrial screens, and has many attractive features. The observer views a circular array of twenty-six coloured filters including a neutral, provided by Tintometer standard glass of high colorimetric accuracy; he rotates the circular array by a knob. A matching neutral filter occupies the centre, and the observer has to find any filter/s in the circle which match the central neutral filter, with the aid of a pointer to indicate his choice. The number of each colour selected is seen by the operator in a window on the side of the instrument and is recorded on a special sheet. Finding the threshold saturation for two colours to match enables a quantitative assessment of colour deficiency to be made. The diagnosis of the type and degree of colour deficiency (including tritan defects) takes only two or three minutes and the test also provides an estimation of the colour matching ability of normal observers. It is unfortunate that the rather high price of the test has limited its popularity in industry.

OWN SURVEY

A total of ninety-seven colour defective observers (fifteen protanopes, thirty deuteranopes, ten protanomalous, forty-one deuteranomalous and one tritanope) took part in the simulated industrial tasks described in this study. Each observer was examined on a number of colour vision tests.

The following tests were used in the battery:

1. Ishihara Test 34 page edition (10th edition)
2. H.R.R. Test
3. Farnsworth-Munsell 100 Hue Test
4. Farnsworth D.15 Test
5. Lovibond Colour Vision Analyser
6. 10/19 Test - Prototype of The City University test.
7. Nagel Anomaloscope

All tests were administered undera standard Macbeth source which provided artificial daylight illumination (Illuminant C). The number of errors made at each test was recorded, and where possible a qualitative diagnosis was made of the defect. The 10/19 test consists of a series of ten displays each containing seven Munsell papers in a circular arrangement, each 7mm diameter in size. The colours are chosen to include protan, deutan and tritan confusions with the central paper. The observer is asked to indicate which of the seven colours in the circular display matches most closely with the central colour. The number of abnormal responses out of a total of ten displays is recorded.

Full details of the performance of observers at the tests is given in Appendix 9 . The numbers of errors for each test is recorded. The Ishihara plates containing numbers visible to the colour defective only and the tracing paths were omitted, hence the total number of plates presented to observers was twenty. The number of vertical crossings made by observers at the D.15 test when plotted on the result sheet is given together with an indication of the axis direction (indicating a protan or deutan defect).

Several authors have stressed the need to relate standard colour vision tests to industrial and occupational performance, SLOAN AND ALTMANN (1951), WRIGHT (1953), FARNSWORTH (1957) JORDINSON (1961), LAKOWSKI (1968). WRIGHT (1953) points out that the usual reason for carrying out colour vision testing is to grade a person's vision for a particular task. He favours a test which, as nearly as possible, simulates the task itself, but points out that "it is comparatively rarely that the task is of a sufficiently limited and clearly defined nature that this principle can be put into practice effectively". A lantern test is a good example of a satisfactory trade test. TAYLOR (1970) recommends trade tests butmakes two provisos:

1. The conditions must be those encountered in the actual situation e.g. dirty cables or poor lights.
2. The results must not be regarded as of a general application but only to the trade situation.

LAKOWSKI (1968) considers that it is more important to discover whether a person can do a specific job than to classify him as a colour defective. Detecting and classifying a colour anomaly is far from adequate for industrial selection; what really matters is whether a deficiency significantly handicaps the person carrying out his work. TAYLOR (1971) stresses this point; he considers that the degree of difficulty which is likely to be encountered in a particular occupation has to be weighed against the severity of the anomaly, when advice is being given. This raises a considerable problem, which LAKOWSKI (1968) has recognised - namely that standard colour vision tests may be of limited value as an index of practical colour ability. After all the tests were designed primarily for scientific purposes as LAKOWSKI (1968) recognises, and their purpose is to act as screening tests to separate colour normals from colour abnormals, and in some cases to classify colour vision defects. Nevertheless Lakowski believes that selection on the basis of colour vision tests alone is still possible for an industrial index.

The severity of a colour vision defect is of far greater importance industrially than the type of defect. Several authorities hold this view, FARNSWORTH (1957), COLE (1964). This raises particularly difficult problems for colour vision testing and its application in industry because few tests provide a reliable quantitative assessment of deficiency and each has its own threshold level of difficulty even for pass-fail. COLE (1964) considers that the pass-fail criteria can be fairly liberal for a wide range of jobs, and notes that there are no standards for colour vision with anything like general acceptance and the pass-fail criteria are chosen often arbitarily. WRIGHT (1953) emphasises how difficult it is to draw the line between those to be accepted and those who must be rejected. There is no doubt that many colour defectives are, in fact, working at industrial colour jobs quite successfully, in situations where failures and errors might be expected. The Committee set up by the Physical Society in 1942 to investigate colouranomalies in industry reported cases and numerous examples have been cited since. The present writer has met several such individuals. The Committee of the 1946 Report recommended that "except where the operations are of an especially critical nature, or where questions of safety are involved, we advocate that doubtful cases should be decided in favour of the candidate, provided that he is warned that he may be handicapped through loss of speed etc." It is not, however, clear what constitutes a doubtful cases and with such a diversity of testing methods available considerable thought and caution is required before a judgement is made.

The ability of colour defectives, who show only mild abnormalities in their colour sense, to carry out certain colour jobs has been recognised, HARDY, RAND AND RITLER (1954), FARNSWORTH (1957), HOGAN (1957), WALRAVEN AND LEEBECK (1957 and '60), DREYER (1969), COLE (1972). COLE (1972) has classified the operations involving colour judgement into four classes according to the kind of judgement made by the observer and the way colour is used. He recommends that all colour defectives should be excluded from operations involving comparative judgements of colour e.g. colour matching or appraisal and analysis. He further advises the colour defective to avoid situations and operations involving the aesthetic judgement of colour e.g. art design, interior decoration etc. But he considers that where connotative recognition of colour is involved in colour coding anomalous trichromats are perfectly able to cope unless the code is unusually complex or their colour vision defect approaches that of a dichromat. Similarly in denotative colour recognition, where colour is used to mark or identify objects, all but the most severe colour defective will be able to perform adequately. CAVANAGH (1955) believes that some colour defectives can safely be entrusted with many specialised colour jobs if they are aware of their defect and avoid very critical work. The same author wonders if some jobs could not be modified to suit even the severe anomaly. He points out that many anomalous trichromats who would not be accepted for certain work in the Armed Forces could be considered safe for similar work in civilian life. PICKFORD (1954), however, takes a more cautious view. He maintains that because many anomalous trichromats are unaware of their deficiency they are a particularly dangerous group because they tend to have confidence in their own colour judgement. Consequently he believes that anomalous types should be excluded from all occupations in which colour vision is of practical importance. WALLS (1959) believes extreme anomalous trichromats to be the most dangerous of the defectives on account of their unstable colour vision.

The wide range of colour industries and occupations involving colour recognition or judgement, and the very variable standards or tolerances that are found within them, make it impossible to recommend a single test for industrial use. Each industry must be considered separately in the light of the colour tasks involved and the possible consequences and importance of errors in colour judgement. Even when this has been done the choice is far from easy because of the limitations of existing testing methods, which have been described. Further discussion of this aspect and recommendations appear in the conclusions on page 413.

FARNSWORTH (1957) has recommended tests "for the purpose of efficient personnel placement in industry," but his suggestions are far from adequate. His industrial classification of colour vision defects into grades is given below:

	PROTAN	DEUTAN	TRITAN	
MILD MODERATE	Protanomalous	Deuteranomalous	Tritanomalous	Anomalous trichromat.
SEVERE	Protanope	Deuteranope	Tritanope	Dichr-omat.

Most anomalous trichromats fall within the mild and moderate groups; a few overlap with the dichromats as severe defectives. He feels that there is no justification for disqualifying the mild defective from occupations such as a pilot, locomotive engineer and bus driver, and the professions of chemistry, biology, medicine and electronics. A moderately or severely colour defective individual, however, must never be placed in a position in which a failure of colour judgement would jeopardize persons or property. Farnsworth recommends the use of the H.R.R. plates, a colour lantern, and the D.15 test to grade the abilities of colour defectives. His classification is given below:

PASSES

	Plates	Lantern	D.15	Normal	
FAILS	Plates	Lantern	D.15	Mild	Defective
	Plates	Lantern	D.15	Moderate	
	Plates	Lantern	D.15	Severe	

He recommends a single test if the job involved is analagous to the test itself - e.g. a lantern test for pilots, and considers that for factory assembly work with colour coded wires, workers are acceptable if they pass the D.15 test. The approach is sound, but no indication of what constitutes a pass and failure at the various tests, is given. Furthermore no evidence is given to support his suggestion that colour codes pose no problem to the moderately colour defective individual, if the colours are clean, reasonably large in size and well-lit. WALRAVEN AND LEEBECK (1957 and '60), HARDY, RAND AND RITLER (1954), VON G. RICKLEFS AND WENDE (1966) have suggested that only those classified as mildly defective on the H.R.R. plates are able to read resistor codes accurately, and the present writer supports this view on the basis of results presented in this study. COLE(1964) claims that there is a strong case for excluding only dichromats and extreme anomalous trichromats (the "mild" defective in Farnsworth classification) to enter all but the most critical colour work. He feels that there is little justification for a more elaborate categorisation and the present writer supports this view.

SECTION III

Industrial Postal Survey and Visits

At the beginning of the study a questionnaire was drawn up with an accompanying explanatory letter. Almost five hundred copies were circulated over a period of two years to representatives of the major industries concerned with colour products in the U.K. Addresses were taken from trade directories and lists supplied by the Research Associations. Most of the questionnaires were sent to large[1] companies but where appropriate a small number were sent to minor[2] ncerns. This enabled an overall general impres ion to be obtained.

The questionnaire was designed to discover three basic facts:

1. The Role f Human C l ur Vision and Judgement in Industry

   To what extent visual colour judgement is made in industry, what jobs require good colour discrimination, and how many people are involved in these occupations.

2. C l ur Visi n Testing Policies in Industry

   The extent to which a colour vision test is given to employees involved in colour work, either at the

1. e.g. E.M.I. (Electrical) Total 29,000 Employees
   Heinz (Food) Total 2,500 Employees on one site only

2. e.g. Robert Stockwell Ltd., London, S.E.1 80 Employees

pre-employment stage or during employment.
What tests are used, to whom they were given and by whom they are administered.

3. <u>Colour Mistakes made which could be, or were, attributed to Defective Colour Vision</u>

   In addition the following questions were asked:
   'Would you be willing for me to make a brief visit to your organisation to assess the role of colour played in your industrial tasks and to discuss these matters briefly with an appropriate person? Whom should I contact to arrange such a visit?'

A space for additional comments was provided.

A complete list of companies who returned the questionnaire is given in Appendix 3. A total of three hundred and fifty questionnaires were received. From this information suitable representatives of the major industries involved in colour work were selected to visit.

A complete list of the companies visited to discuss the matters further, and to view the processes involved is given in Appendix 4.

The following sections outline the conclusions from the major industries concerned.

BRICK INDUSTRY

Brick colours vary very widely today. A few of these are illustrated in figs.

> Black, White, Ivory, Buff, Dark and Light Grey, Green, Yellow, Cinnamon, Lilac, Lavender, Purple, Blue, Heather, and Straw, as well as a complete range of browns, reds and orange bricks are some of the common single coloured bricks. Multicoloured bricks are also widely used e.g. the dappled or brindled brick.

A number of factors determine the final overall colour of a brick. To a large extent the choice of raw materials is a dominating factor, but the method of manufacture also affects the final colour considerably. The temperature and duration of heating during manufacture can radically change the colour of a brick. Hence red bricks which are overheated become brown or purple. The degree of oxidation or reduction in the heating process also causes wide colour variations. Hence bricks on the outside of a kiln may become light pink whereas those further in assume a final yellow appearance and bricks at the centre of the kiln become purple. Pigments can be added to change the basic colour during manufacture and surface glazes can be applied to the final product to alter its colour. Good colour vision is therefore a very necessary requirement for personnel involved in grading or sorting bricks or in the choice of bricks.

Correspondence with the East Midlands Brick Association confirmed that "brick manufacturers are involved in tasks concerning colour judgement", and yet it was surprising that few of the brick manufacturers contacted realised the importance of good colour vision for these jobs. A large number of brick manufacturers were contacted with the questionnaire although only three replied, indicating perhaps the lack of concern for this aspect of their work. Of those who completed the questionnaire, one manufacturer mentioned a total of fifty persons being involved in colour judgement. Of these sixteen were kiln firemen and twenty-eight were brick packers. A test for colour vision was not given to date but arrangements were being made to include one for prospective employees. Another large brick manufacturer indicated that twenty-five people were involved in sorting work which required good colour judgement. The Ishihara test had very recently been introduced in this company. The other company who replied considered the problem to be minimal since few people had to exercise colour judgement. An obvious lack of awareness of the potential problems of defective colour vision in this industry was evident, and clearly action must be taken on this matter.

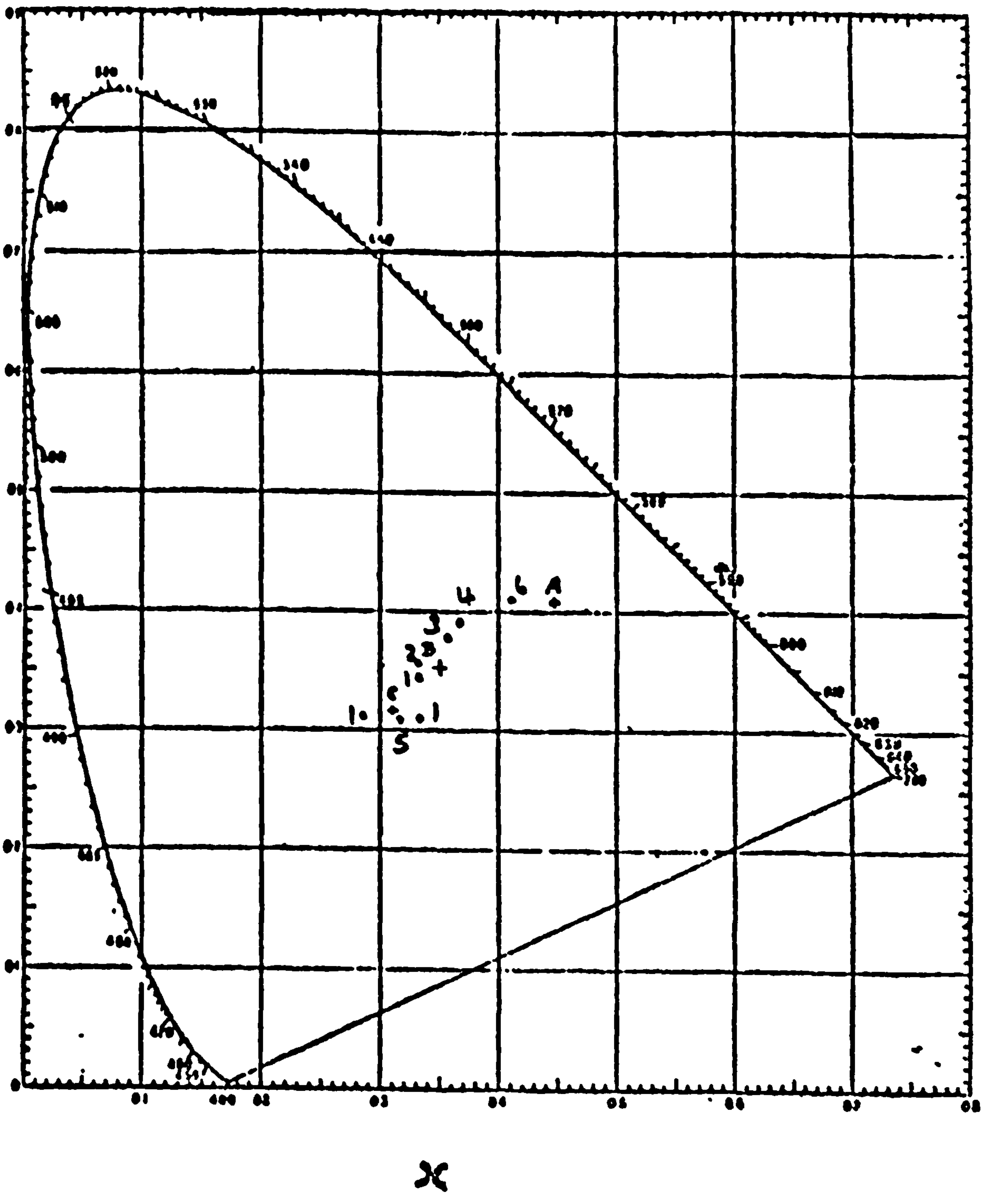
Data collected by a 3rd Year student at The City University in 1976 indicates that many of the colours of bricks are likely to cause problems for colour defective observers. See Figure 1

BRICK NUMBER	DESCRIPTION	MUNSELL COLOUR DESCRIPTION	CHROMATICITY CO ORDINATES		
			x	y	Y
1	Dover Cream	5Y/8/4	0.3650	0.3826	0.5910
2	Stock	5Y/8/8	0.4158	0.4378	0.5910
3	Golden Brown	10YR/7/8	0.4399	0.4164	0.4306
4	Natural	7.5YR/7/8	0.4415	0.3996	0.4306
5	Red	5YR/6/10	0.4921	0.4022	0.3005
6	Robin Hood Red	2.5YR/5/8	0.4795	0.3758	0.1977
7	Purple	7.5RP/4/4	0.3612	0.2963	0.1200
8	Dark Red Multi	7.5R/4/6	0.4415	0.3340	0.1200
9	Lincoln Velvet	7.5R/6/4	0.3692	0.3291	0.3005
10	Lilac	5RP/8/1	0.3100	0.3150	0.5910
11	Grey	5Y/6/1	0.3350	0.3400	0.3005
12	White	5Y/8/1	0.3300	0.3350	0.5910
13	Ebony Black	5RP/2/1	0.3250	0.2950	0.03126
14	Blue	7.5B/4/4	0.2388	0.2704	0.1200
15	Dark Brown	10YR/4/2	0.3660	0.3590	0.1200
16	Chocolate Brown	10YR/5/4	0.3995	0.3840	0.1977
17	Mixed Cream	10YR/8/4	0.3701	0.3674	0.5910
18	Dappled	7.5YR/8/2+ 2.5Y/8/6+ 2.5GY/8/2+	0.3395 0.3969 0.3327	0.3379 0.4009 0.3555	0.5910 0.5910 0.5910
19	Multi Stock	7.5RP/5/4+ 10R/5/8	0.3515 0.4713	0.3024 0.3575	0.1997 0.1997
20	Berry Moulded Dark Multi's	2.5R/4/8+ 10YR/7/4+ 10YR/6/4+ 10BG/3/2	0.4472 0.3778 0.3861 0.2660	0.3031 0.3719 0.3767 0.3050	0.1200 0.4306 0.3005 0.06555

TABLE 2 COLOUR CHARACTERISTICS OF SOME COMMON BRICKS

(Taken from Miss A. Rawson's 3rd Year special study 1976 The City University.)

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 1 Chromaticity co-ordinates of colours of Building Stone

C.I.E. CHROMATICITY CO-ORDINATES

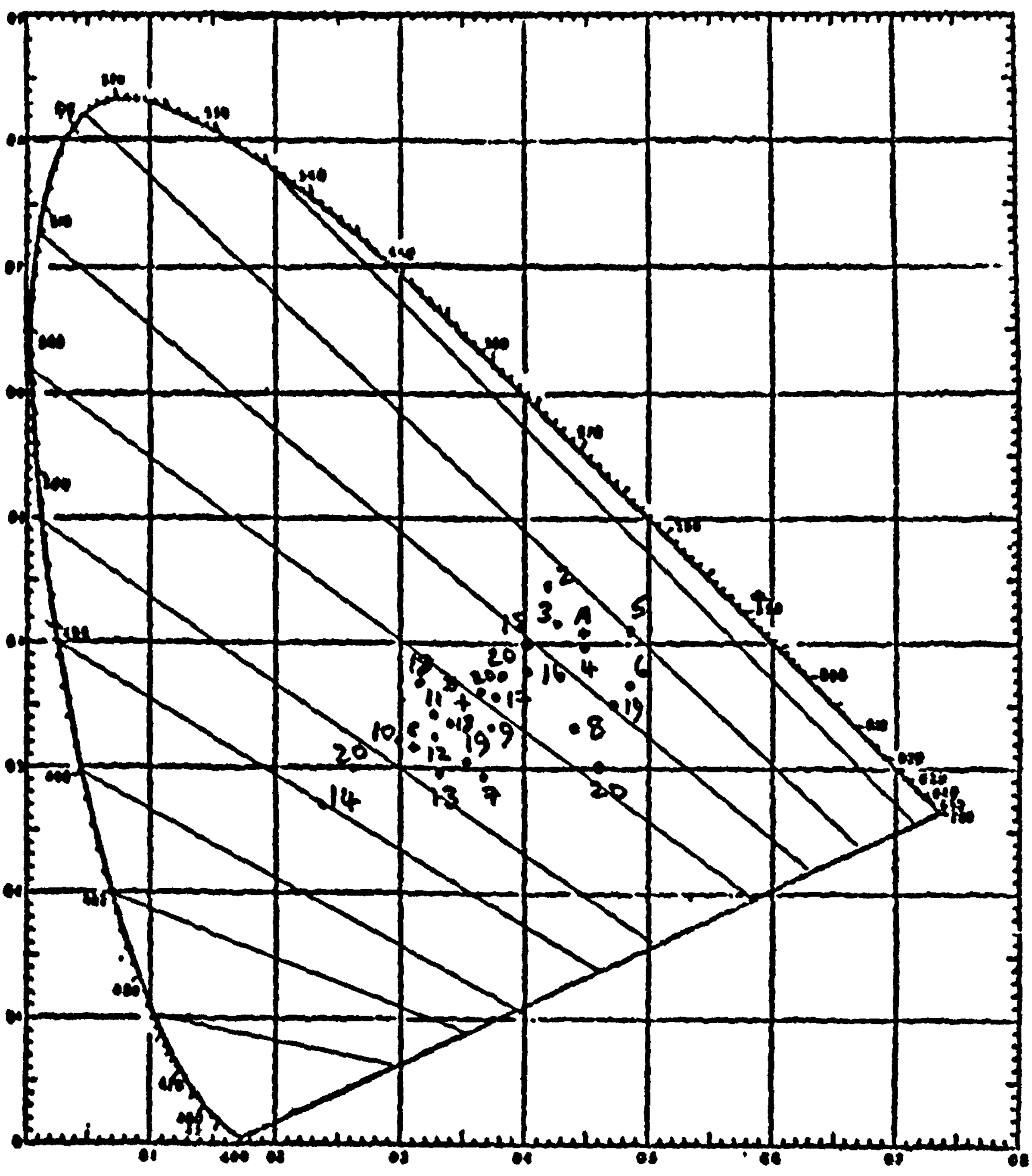
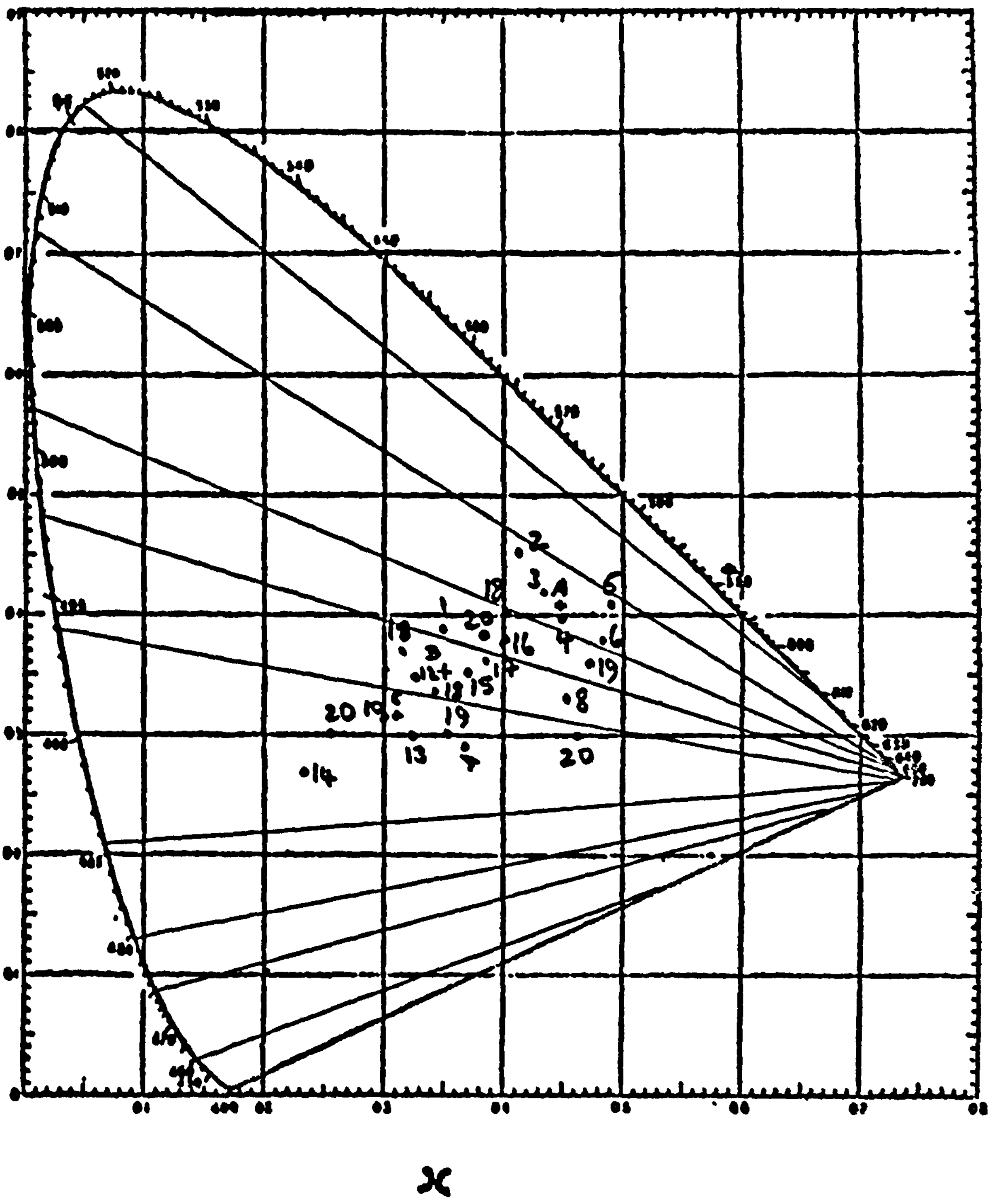


Figure 2 Brick colours and Deutan Confusion Loci

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 3 Brick colours and Protan Confusion Loci

Possible Confusions of Brick Colours

by Colour Defectives

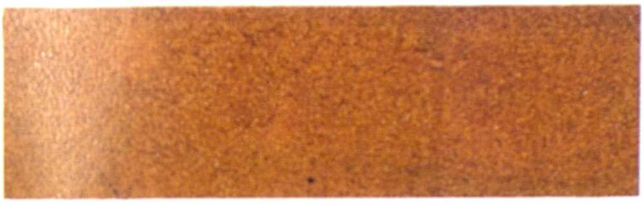
Deutans

2/5	Stock/Red
3/4/6	Golden Brown/Natural/Robin Hood Red
2/3	Stock/Golden Brown
18/19	Dappled/Multistock
16/8	Chocolate Brown/Dark Red Multis
18/20	Dappled/Berry Moulded Dark Multis
12/19/7	White/Multi stock/Purple
18/9	Dappled/Lincoln Velvet
18/15	Dappled/Dark Brown

Protans

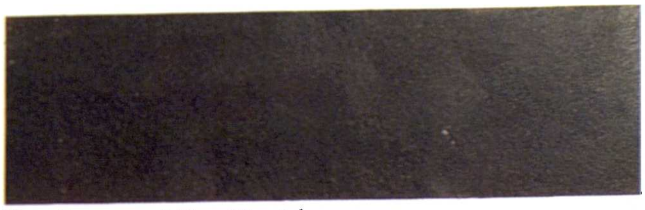
2/5	Stock/Red
18/4/6	Dappled/Natural/Robin Hood Red
16/19/20/1	Chocolate Brown/Multi stock/Dark Multis/Cream
18/20/8	Dappled/Dark Multis/Dark Red Multis
12/18/9/20	White/Dappled/Lincoln Velvet/Dark Multis
20/10/13/19/7	Berry Moulded Dark Multis/Lilac/Ebony Black/ Multi stock/Purple.

BRICK COLOURS


Haze Br wn Sand Fa ed

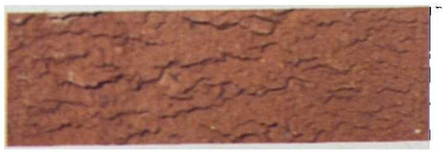

Purp e Sand Faced


Harvest Br wn Sand Faced


New Brunsw ck Sand Faced

Fine sandfaced

Sandcreased machine-made



Coarse vertical dragged

Smooth

Fine sandfaced

CERAMICS INDUSTRY

Hue and saturation discrimination play a major role in colour assessment work in all areas of the ceramics industry - porcelain, sanitaryware and the manufacture of tiles.

Almost all colour judgement and colour matching work is visual, and the leading manufacturers consulted did not forsee a move towards instrumental methods in the near future, except perhaps in the sanitaryware field. The most critical colour matching tasks seem to be in the manufacture of ceramic glazed tiles with sanitaryware following closely behind. A wider tolerance for colour is accepted in the tableware area of the porcelain industry where the main problems are associated with maintaining whiteness.

The British Ceramic Industry Research Association have a keen interest in the colour matching problems of the industry and a useful visit was made to discuss these aspects with Mr. F. Malkin who is responsible for research work on colour.

Seventeen questionnaires were returned - eight from porcelain companies and the rest divided approximately equally between the tile industry and sanitaryware manufacturers.

Porcelain

The findings here were mixed - ranging from awareness of the problems of defective colour vision to absolute indifference. About sixty percent of the eight manufacturers who completed the questionnaire did not test the colour vision of their staff, yet most relied on the visual colour judgements of their employees, particularly in the painting, decorating and inspection areas. In most companies standard items are held, even to the extent of a "substandard" being available on each bench, for a direct comparison with production goods. A few companies mentioned that colour did not play a part in their processes, and this seemed surprising.

One large porcelain company, of international repute, who employ over two hundred people in key colour positions, did not give a colour vision test to employees. A visit to the company was made and even after a discussion on the matter, in which the potential problems that might arise if a colour defective was employed in critical colour work were outlined, the management were still not convinced of the desirability of testing colour vision. Strangely they have never experienced problems and as with many other manufacturers contacted during the study, they are reluctant to change their established policy without very good reason.

Two important errors in colour judgement made in one large pottery works by individuals who were later found to be colour defectives, alerted the management to consider the potential problems of employing colour defectives. The

Ishihara test for screening was subsequently introduc ed in this company. In one case an error was made in the decorating department when an enameller was unable to judge the strength of a colour. A further example occurred in the warehouse when a new employee was unable to make correct quality assessments.

Large numbers of people with colour defective vision are unlikely to be found in this industry because most of the painters and decorators are women. However, a large propor tion have a long emplyment record at the job and a great number were taken on for work several years before the introduction of a colour vision test. Brief encounters with these employees during two visits to porcelain companies reinforced this fact. There is a strong family tradition of employment in this industry.

Sanitaryware

Colourmatching is a most important feature in the production of bathroom fitments where several separate items must match for colour. Problems in controlling this arise especially when the different items are producted in different factory locations e.g. washbasins, pedestal and washbasin itself. All colour judgements are made visually, but care is usually taken to ensure that the conditions of viewing are standardised.

A visit was made to one leading sanitaryware manufacturer. Matching of colour glazes prior to coating is at present still done visually by Quality Control inspectors, but it is anticipated that instrumental methods will take over in the near future. Corrections are made using computerised techniques.

A special colour matching room is set aside for all visual analysis. Standard specimens of finished products are held and all judgements are made by a comparison of the production sample with the standard under conditions of controlled artificial daylight illumination. Four people are involved in this work. Before the room was equipped for this purpose samples were compared outside in the open-air and customer complaints of mis-matching averaged one a week. The use of a standardised room has considerably reduced these complaints to three or four a year. Matching standard colour plaques (4"x4") to large pieces of sanitaryware was found to be unsatisfactory so that all matching is now done between complete items.

Considerable co-operation has taken place between individual companies recently, on the difficult problems of colour control, and tolerances have been compared. Wider tolerances are generally accepted for the deeper colours - of the order of ± I.N.B.S. Units.

The company visited was aware of the problems which might arise if colour defective persons were employed in this work. They were also aware of the deterioration of colour vision with age, but did not feel that this was a sufficiently large problem to warrant taking any measure against it. The Ishihara test was given to all personnel involved in colour work.

Several companies indicated in the questionnaire that they were aware of the limitations of visual colour judgement and differences of opinion that arise between observers. Three out of five sanitaryware manufacturers who returned the questionnaire did not give a colour vision test to employees concerned with colour work. One company, who had twenty operatives involved in final colour inspection work mentioned that three tests - the H.R.R. plates, the Farnsworth-Munsell 100 Hue Test and the D & H Colour Rule were used to test their employees but this was carried out by the British Ceramic Research Association. Subsequent enquiries revealed that the B.C.R.A. are pleased to provide a colour vision testing service to member firms who request it.

Tiles

Correct colourmatching is an essential feature in the production of glazed tiles. The eye is quick to notice small colour differences in a composite collection of tiles as they occur, for instance, in a bathroom setting. It is partly for this reason that visual methods are used in comparing production samples with standard tiles in the manufacturing process. In addition, mottled effects and reflection/refraction from glaze bubbles make instrumental colour measurements difficult. Metamerism and fluorescence are seldom problems and the quantity of pigment used is laid down in a recipe or formula.

Difficulties in maintaining a given colour do arise during the manufacture of glazed tiles and a number of factors in the process do alter the final colour. In particular the temperature and length of time of firing affect the final colour, and subsequently the position of the sample in the kiln is important. Manufacturers often relate the position inside the kiln to the colour of the final product. In general tolerances for greys and whites are smaller than for coloured tiles. An unexpected ignorance of the potential problems of employing colour defective people in this section of the ceramics industry was evident.

Four leading manufacturers of glazed tiles returned the questionnaire. Of these only one took the precaution of testing personnel for defective colour vision. In one of these companies twelve people are involved in quality control colour assessment. Another company did not consider that a colour vision screening test was necessary because they said that a colour vision defect in an operative would soon be detected. They further justified this position by mentioning that all work was checked. This information reveals again how timely this study had proved to be, and the reader may wonder how long this state of affairs maybe permitted to continue.

A visit was made to the premises of one of the leading tile manufacturers in the world. In this company no colour vision test is given, yet it is the sole responsibility of one individual to decide whether or not a batch of tiles meets the inspection requirements before despatch and correct colour is a major consideration.

It appears from this information that within the ceramics industry tile manufactures are most at risk to the problems that defective colour vision must certainly present.
Mr. F. Malkin[1] of the British Ceramic Industry Research Association has confirmed this conclusion and the British Ceramic Manufacturers' Federation[2] and the National Federation of Clay Industries[3] were both contacted and were not aware of any national policies concering the colour vision testing of personnel engaged in colour assessment within the ceramics industry.

1. Personal telephone conversation 5th July 1976
2. Personal written communication 7th June 1974
3. Personal written communication 9th March 1976.

The standard method of viewing ceramic tiles reco mended by the B.C.R.A. is shown in fig. 4 . This method is frequently adopted by manufacturers.

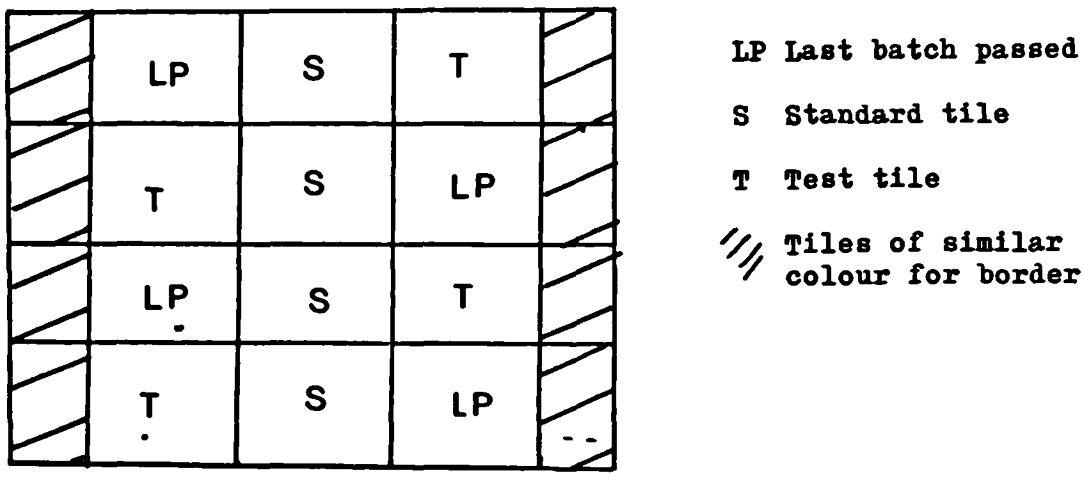


Fig 4

CHEMICAL, PLASTICS AND OIL INDUSTRIES

A nhmber of analytical and a few colour matching jobs procedures in these industries require good colour discrimination. In addition colour coding of industrial cylinders and pipelines would present problems to colour defective individuals. Most colour work is restricted to laboratory personnel and quality control workers, but a few members of production staff are required to exercise colour judgement of coloured plastic materials.

Questionnaires were returned by twelve representatives of chemical, plastics and oil manufacturing concerns. The majority were aware of the need for good colour vision and the Medical departments gave an Ishihara test to appropriate employees. In two instances the I.S.C.C. colour aptitude test was also used by technical staff. Correspondence with the Chemical Industries Association (Occupational Health Committee of the Chemistry Industry Safety and Health Council) revealed that

> "no industry-wide policy has been establi shed for colour vision testing since the need would vary from firm to firm. It would be up to individual companies to develop their own standards although if a particular need within the industry were identified we would obviously be circulating advice through our Medical Committee."

In one large plastics manufacturer a hundred and fifty people were involved in colour judgements on the Quality Control side and another company employed almost a hundred colourists. Three leading oil/petrol companies mention a number of procedures or processes which demand careful colour identification. These include the areas of oilfield engineering, seismology, paleontology, geophysics, and chemical manufacture and oil refining. In one company almost a thousand deck mariners (seafarers) were required to identify coloured signals and the Ishihara test was supplemented by a lantern for these people. Marine engineers were given a coloured cable to identify in addition to the Ishihara test.

A very large number (1,000) of laboratory assistants and control chemists are employed at the Milk Marketing Board and frequently rely on colour changes in analytical procedures, various tests to determine the hygienic quality of milk together with the razurine blue test and methylene blue test demand good colour vision. The Antibiotic testing using T.T.C. indicator also fall into this category. Laboratory personnel at the Headquarters are screened with the Ishihara test, but testers at the boards throughout England are not necessarily dairy tested. Hence the example of a female dairy tester in East Anglia who frequently failed samples using the hygiene test and proved to be colour defective. Most of the dairy testers are women so the likelihood of large numbers of colour defective testers is remote. Information was given on the questionnaire of a senior liason chemist who is

> "partly colour blind but is fully aware of the implications e.g. for acidity testing he cannot use methyl orange indicator."

It was surprising that cases of acquired colour vision defects resulting from the inhalation of toxic industrial fumes were not reported in these industries. No doubt cases have arisen.

DYEING AND TEXTILE INDUSTRY

Colour is of such paramount importance to the dyeing and textile industry that there can be few jobs where the visual discrimination of colour is not critical to the production process, at least at the present time. Instrumental methods are gradually replacing the need for the experienced dyer or colourist, and it is possible that within ten years the subjective element will be markedly reduced. However, the final assessment of acceptability is a visual decision by the customer, and it is therefore difficult to imagine a situation where the observer's appreciation will not be considered.

Extensive enquiries were made within the textile and dyeing industries, particularly in the North of England. Questionnaires were returned by thirty-two industrial and research establishments concerned with the dyeing and manufacture of textiles. Visits were made to two carpet factories, two dye houses, one textile manufacturer and one company concerned with the making-up of dyed garments. In addition, visits were made to three research organisations concerned with textiles (hosiery, cotton and wool), and the research department of two large international textile companies.

Before 1930 all work in the textile industry involved visual determination; when recording spectrophotometers were developed in the 1930's, and computer in the 1940's, considerable attempts were made to develop sophisticated instrumental methods for the colour assessment of materials to replace the visual element with the inevitable variability. Certain sectors of the industry, in particular the research departments of the larger companies, and the Research Associations, have developed considerable expertise in this field. The literature on the subject is now vast.

Visual Colour Matching

The eye is very sensitive to small differences in colour and can very quickly detect when two colours do or do not match each other. The magnitude of a mis-match and the direction in which this discrepancy lies is more difficult to judge. The dyer or colourist is frequently asked to dye yarn or fabric to match, as accurately as possible, a small sample provided as a standard or master. Drawing on his previous experience and his book containing previously dyed samples with their recipes, he must produce a match which is commercially acceptable to the customer. The judgement is usually made visually, often by a dyer working in isolation. In arriving at a proper match three factors have to be taken into consideration - the shade or hue of the colour, the strength or depth of colour or saturation and the lightness of the colour. The procedure is approached in stages, very carefully at first because of the obvious difficulties of removing dye once it has been added. Additional problems arise if the standard sample is made of a different material or is of a different weight or weave from the required goods. The final use to which the material will be put must often be considered, as must the degree of fastness required. A good dyer will be able to produce an appropriate dye formula or recipe within five minutes. The match obtained is termed a "commercial colour match" - a match as near to the standard as it is possible under the circumstances, usually deviating slightly from the standard, but by an amount that will probably not be detectable to most inexperienced observers. The colour difference that can be tolerated will vary from company to company and may depend very largely on the customer and the price he is prepared to pay. Understandably the closer thematch, the higher the price. Some customers have higher standards than others; what might be accepted by company A as a commercial match would be instantly rejected as poor work by company B. McLAREN (1970) estimates that professional colour matchers must inevitably reject about twenty-five percent of acceptable samples; the economic consequences of this are obvious.

Viewing conditions and other factors

The problem is further complicated by the viewing conditions which affect the visual estimation of colour differences. The most important of these are:

1. Illuminant type and intensity
2. Size of viewing field

3. Colour of background

4. Line of demarcation

5. Texture differences

6. Iridescence

7. Fluorescence

1. Illuminant

Natural daylight has been preferred for many years - the north sky being considered ideal. Because of its variability in both quality and quantity recommendations for artificial daylight sources have been made and are used almost universally today. The C.I.E. made specfications in 1931 and this was followed ten years later by the British Standard 950 Part I based on standard illuminant C. More recent recommendations for a source with a correlated colour temperature of 6500°K (C.I.E. standard illuminant D.65) have been adopted. The latest British specifications for artificial daylight for the assessment of colour are given in British Standard 950 Part I (1967) "Illuminant for colour matching and colour appraisal". The specification requires that the chromaticity of the light shall lie within certain limits and the difference between the spectral distribution and that specified shall also be within certain limits. The chromaticity co-ordinates of the centre are given as:

$$x = 0.3127, \quad y = 0.3291$$

2. Size of viewing field

This is important because for small visual angles the image

is formed within the area of macular pigmentation of the retina, and because with the increase in visual angle the perception of colour differences is also increased.*
BALIKIN (1941) illustrates this point by the example that when two small samples about one inch square are cut from large sheets that differ in colour, the visual appearance of colour differences may be several times smaller for small samples. It seems that the visual system integrates colour differences throughout the extent of the retinal coverage.

3. Colour of background

The colour of the background especially when each sample has a different background colour, affects colour difference estimations. This is due to the phenomenon usually described as simultaneous contrast. For maximum perceptibility of small colour differences, the colour of the background should be similar to the colour under comparison. A neutral grey of approximately the same lightness as the sample is usually recommended.

4. Line of demarcation

The line of demarcation between two coloured samples plays an important role in diminishing or enhancing the magnitude of colour differences. BALIKIN (1941) reports that the samples which differ chiefly in lightness, require a slight colour difference when they are separated by a wide area of

*and the eye becomes tritanopic for very small angles of some other colour. Where no line of demarcation exists the apparent colour difference for the same pair may be increased by a factor of ten or more. MALKIN (personal communication 1975) notices similar effects.

5. Texture differences

Apparent colour changes can be introduced by texture differences. Different stiches in knitted garments made of the same yarn can show apparent colour differences which are often sufficient to require separate dyeing in order to make the result look identical. (Mr. SPENCER personal communication 1975).

6. Iridescence

Themethod of presentation is very important. Iridescence occurs when one area appears different in colour depending on the angle of view. Although iridescence is usually present to some extent, an excess will cause difficulties in colorimetry and in visual assessment.

The I.S.C.C. were responsible for setting up a sub-committee to consider standard practices for the visual examination of small colour differences, which reported on this matter in 1971. The recommendations cover the spectral photometric, and geometric characteristics of light sources, illuminating and viewing conditions, sizes of

Specimens and general procedures to be used in the visual evaluation of colour differences of opaque materials. The recommendations are reported by HUEY (1972).

Instrumental Colour Matching

Objective assessment of colour differences has gained considerable popularity over the past twenty years. Many industrialists believe that instrumental methods will be employed almost universally within ten years. Others, particularly the smaller concerns, continue to put their faith in the human eye as the final arbiter for shade assessment. One of the main difficulties with instrumental methods is the need to use a universal formula which accurately and objectively depicts the colour differences between two samples as seen by an average observer. Such a formula has yet to be devdoped; meanwhile existing formulae, which are far from satisfactory,have to be used. There is, at present, a considerable lack of agreement between visual assessment and instrumental prediction of colour differences. Since the final judgement is a visual one, made by the customer, it seems inevitable that the visual aspect will continue to play a significant role in the matching of textiles despite the move towards instrumentation.

Special Difficulties

The difficulty of whites

Most textile fibres, particularly natural fibres, are slightly yellow. Colour traces have traditionally been removed by chemical bleaches, or by adding a small amount of blue dye. Since 1940 the use of fluorescent or whitening agents has become popular. These absorb in the ultra-violet range only and convert the U.V. light to blue light which is emitted as fluorescence in the range 400 - 500 nm. This blue light adds to the normally reflected light and raises the average level of the reflectance curve, flattening it slightly also. The measurement of fluorescent substances raises additional problems in colorimetry.

Metamerism

Metamerism, the phenomenon of having two samples matching under at least one illumination and being a mismatch under at least one other illumination, occurs when different dyes are used in two samples. Care must be taken particularly when different fabrics are used in close association to ensure that they are metameric pairs.

Age of the observer

The effect that age changes in the ocular media have on visual assessment particularly that of near-whites is important. WRIGHT (1946) showed that the chromaticity of a given white point changes with age. The variations in normal colour vision between the young and elderly are well-known and the industrial significance of the deterioration of colour discrimination with age has not been entirely forgotten. In a paper concerned with colour vision in industry TIFFIN AND KUKN (1942) mentioned the deterioration in discrimination between red and green for middle-aged observers. Others, including GILBERT (1957), have shown a steady decline in the scores obtained on the I.S.C.C. Colour Aptitude test with age, and reported a reduction in sensitivity to blue and green in the elderly. The reduction in sensitivity to colours is attributed to the increase in opacity and density of the ocular crystalline lens. [LAKOWSKI (1962)] WARBURTON (1954) considered the variations in normal colour vision in relation to practical colour matching ability. He argued that since the age differences can be compared to putting a yellow filter in front of the eye, their effect in practical colour matching is very similar to that of varying the colourtemperature of the light source. Warburton maintains that the influence of age differences is considerable and corresponds to that of changing the light source over a colour temperature range of 4000K. Thus standardization of the illuminant for colour matching is of very little value unless the observer is standardized around the average pigmentation value. He suggested that an observer aged approximately forty years would give a close approximation to the average at least for large field work.

Several companies who replied to the questionnaire mentioned differences of opinion in the colour matching of metameric* pairs, due to ageing effects. Two companies reported that older people tended to match samples redder than young people, and a number indicated that they were aware of the physical causes of these differences. The question of ageing effects on colour discrimination was always raised during personal visits and it appears that most of the larger companies are aware of these differences; WARBURTON (1954) confirms this. Very little attempt is made, however, to use this knowledge. One company reported instrumental colour matching is to be introduced to reduce the human element, and this aspect is presumably one which will assume less importance if objective match prediction does replace the human observer in the near future. Meanwhile the social and economic factors must not be forgotten. It might be argued that the expertise gained over the years by an experienced dyer is sufficient to off-set the changes in colour discrimination. Certainly few companies would be prepared to restrict colour matching to those in the age range thirty-five to forty-five, for purely economic reasons. McLAREN (1960) has described a simple test for detecting differences among colour matchers, and various companies have reported using the Davidson-Hemminger Colo r Rule for this purpose. McLAREN (personal communication 1976) reports that age differences have little practical consequence; he found that colour matching by older observers (up to sixty-two years) is no less reliable than for young observers, but this might be disputed. It is strange that in days when so much care is taken over illuminants, so little thought should be given to the visual characteristics of the observer.

From the visits made to dye houses and textile companies and the information provided in the questionnaires it appears that many people are involved in the visual colour judgement and assessment in the textile industry. In the production process numerous workers may be involved, although individuals below the position of foreman may not be directly responsible for colour work. A higher standard of colour matching is required in dyeing than in printing because the print often hides small colour differences. Very close matches must be maintained for plain dyed cloth.

The 1946 Report of the Physical Society on Defective Colour Vision in Industry describes a number of areas within the textile industry where good colour vision is required.

Cotton

In the cotton industry colouring is usually done after manufacture. Grading of cotton in its raw state involves the detection of small variations from a standard white. Damage by exposure to weather, in particular frost, and insects and fungi may cause discolouration. The best cotton is the brightest and whitest so that careful grading on the basis of colour is important, not only to detect differences in quality, but also to maintain uniformity. Cotton buyers must also have good colour vision. In the linen industry weavers use yarn supplied to them, the colours having already been decided, so there are few instances where good colour vision is required.

Woollen fabrics

In the woollen trade, the colours are combined and blended in the weaving process.

Hosiery

The matching of stockings in pairs and the detection of faults, calls for a high degree of colour discrimination.

Large numbers of individuals may be involved in colour decisions within textile companies, particularly in the larger companies. The numbers involved varied considerably in the questionnaires returned. One large dyeing company mentioned six hundred people being required to see small colour differences and another five hundred. Whereas several smaller companies employed onlythree or four people on colour judgement in the dyehouse and quality control areas. A company concerned with the production of woollen yarns employed forty people on critical colour work. One large textile firm mentioned that seventy to eighty percent of staff must show a general awareness of colours and at least sixteen percent must have very good colour matching ability.

A company concerned with dyes described the following areas and numbers of people as being involved in critical shade matching:

Dyehouse laboratory - formulation of recipes 7

Experimental dyehouse - dyeing samples 2

Dyers office - shade matching of bulk production 8

Quality control 2

Another dyeing and colour printing company involved in fabrics reported that since their whole business is concerned with colour, half of the three thousand employees must be able to identify colours correctly. Typical jobs involved include the general manger, works manager, salesmen, sales manager, chief chemist, colourists, warehouse and laboratory staff, dyehouse staff, printers, research and quality control personnel.

When large quantities of fabrics must be dyed the most important colour problem is the accurate repetition many times over of a standard colour or pattern. It is obviously important that shade variations do not occur within the width and length of the fabric. Additional problems arise in the making-up of garments using components which are made of different fabrics since different materials take up dyestuffs to different extents. These problems were discussed during a visit to a company who assemble garments for a large chain store. The components are dyed separately before they reach the making-up stage, and particular difficulties in shade matching are experienced, e.g. matching up elastic and lace and man-made materials for ladies underwear.

Colour Visbn Testing

There appears to be no central policy for colour vision testing within the textile industry[1,2]; each company makes its own decision on the matter. Of the companies contacted through the questionnaire, nineteen tested colour vision with the Ishihara plates and five companies did not use a colour vision test at all. Large organisations frequently used more than one test including the Farnsworth-Munsell 100 Hue test or the D-H Colour Rule (often for colour normals). The H.R.R. plates were used by one or two companies, but the I.S.C.C. Colour Aptitude Test does not seem to be popular in the textile industry. Trade tests were rarely used except for electricians. Several people indicated dissatisfaction with the Ishihara plates. One large organisation said they had "lost faith" in the test because it was too severe. Another mentioned that "it has a lot to be desired."

The five companies who used no test at all were all concerned

1. Personal written communication with Technical and Education officer, Society of Dyers and Colourists 16th January 1974

2. Personal written communication with Lambeg Industrial Research Association (formerly Linen Industry Research Association) 17th June 1974

with dyeing textiles. In one company concerned with the dyeing of yarns, two dyers, two colourists and seventeen dyehouse operatives were required to make colour judgements. In another only five people were involved. The numbers were not always small; in another dyehouse ten bleachers and finishers plus five quality control personnel were required to make critical colour decisions and a further twenty inspectors of cloth for faults also had to be aware of colour differences in finished fabrics. Fastness assessment, fashion and design were other areas where colour judgement was necessary.

Two large retail groups for clothing also filled in questionnaires. Both mentioned that managerial staff and those involved in buying and selling mechandise would need to distinguish colours, but only one company gave a colour vision test. The colours involved for men's clothing might easily include colours which would give trouble to a colour defective - dark greens, browns and various shades of grey. Laboratory cloth technologists and technicians are also involved in colour work. The three Research Associations (concerned with hosiery and knitted fabrics, cotton and wool) visited all offered colour vision testing facilities and advice to member firms.

A number of mistakes that could be attributed to defective colour vision were described and a few cases of colour defective individuals who were working in the industry were reported. A comment made by the manager of a large dyehouse indicated thought on this subject:

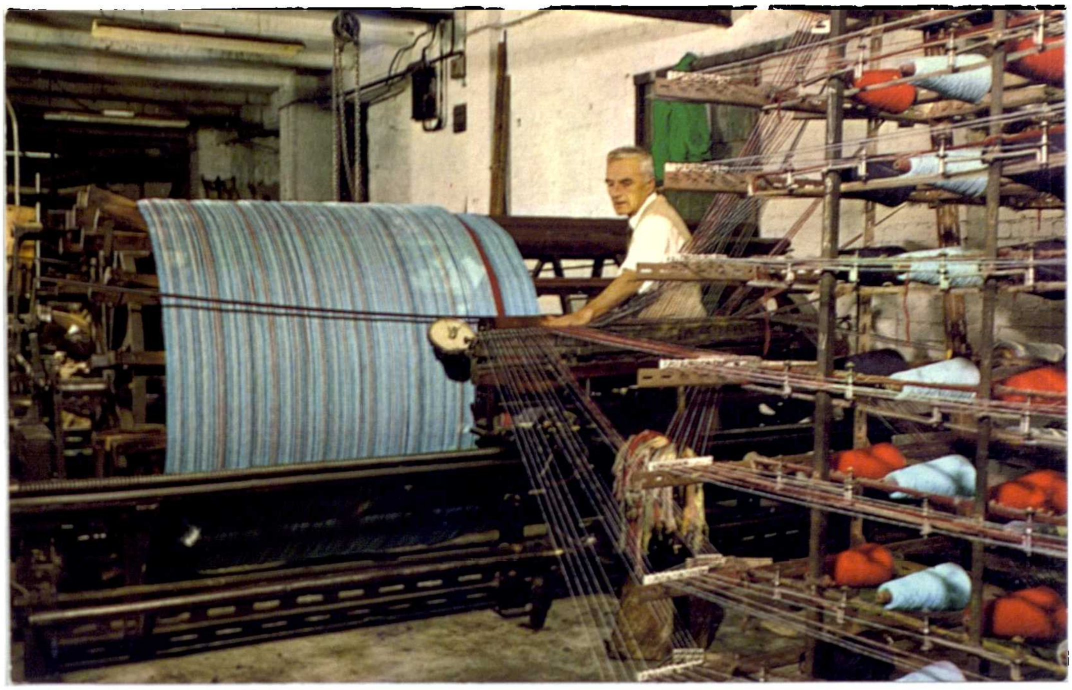
> "it would be interesting to see how known colour defectives cope with industrial colour situations to see whether they can adjust; we automatically refuse employment if any defect is discovered, but I would like to think that certain colour defective people could work with us if they could overcome their defect."

The question was possibly answered by another company reporter who said that individuals showing slight defects in colour vision had been employed, but their abnormality was rapidly detected because of their conflicting ideas with the existing specialists who had normal colour vision. A company concerned with dyeing wool also reported difficulties in the matching and assessment of colour differences by staff showing mildly abnormal colour vision before screening methods (the Ishihara test) was introduced. Several instances of wrong recommendations in matching threads to fabrics were reported by a company concerned with the making up of dyed goods. The Research department of a large textile manufacturing company told of several cases of acquired disturbances in colour vision and were aware of changes in colour vision as a side-effect of some medications. The employment of a colour defective foreman dyer who had somehow missed the colour vision test at the initial interview was reported; the dyer left the company soon after the discovery of his defect. One respondent felt that most mistakes in in textile shade matching and colour assessment probably resulted from stress and fatigue situations rather than defective colour vision since it was the policy in most companies to screen for colour anomalies.

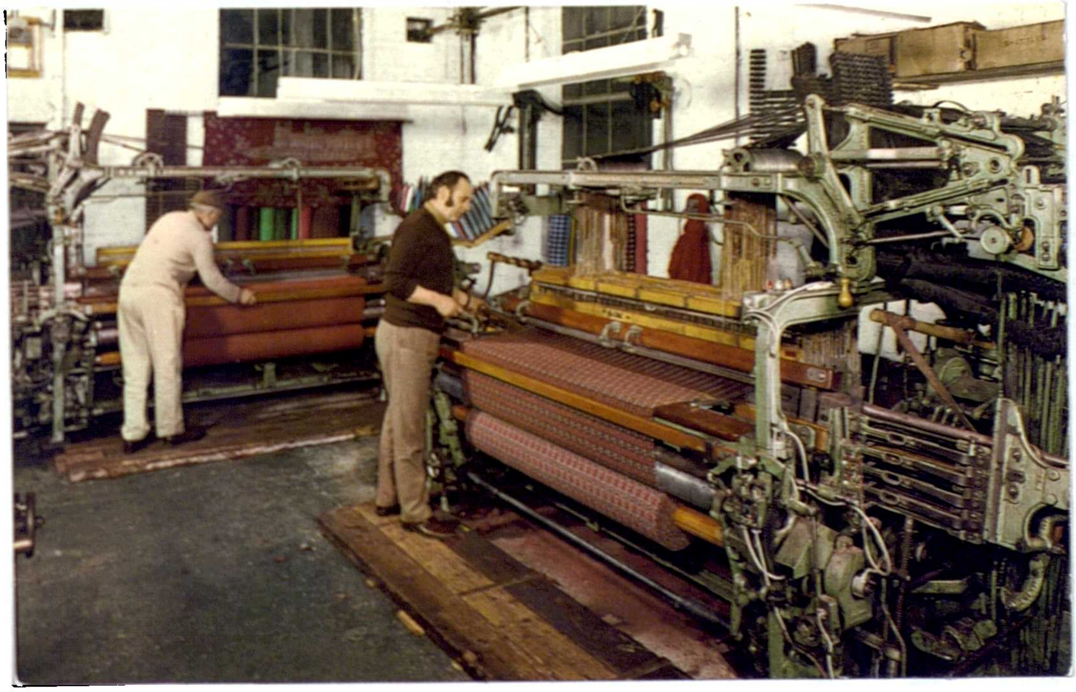
Colour Processes in a Welsh Woollen Mill

Willeying

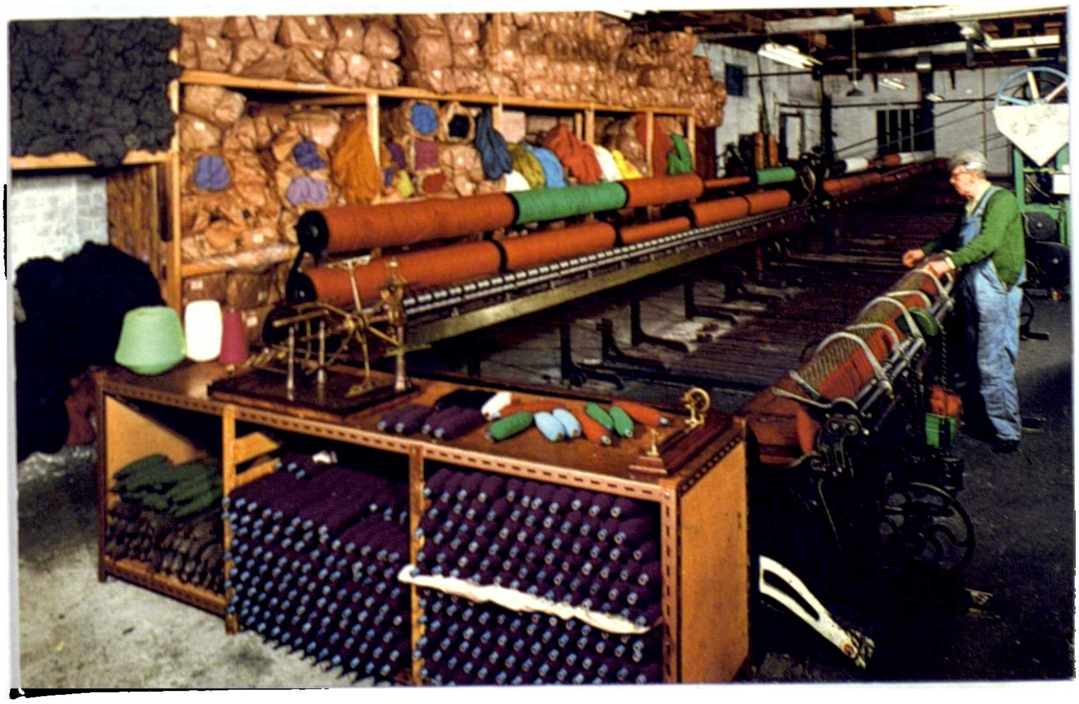
Winding



Warping

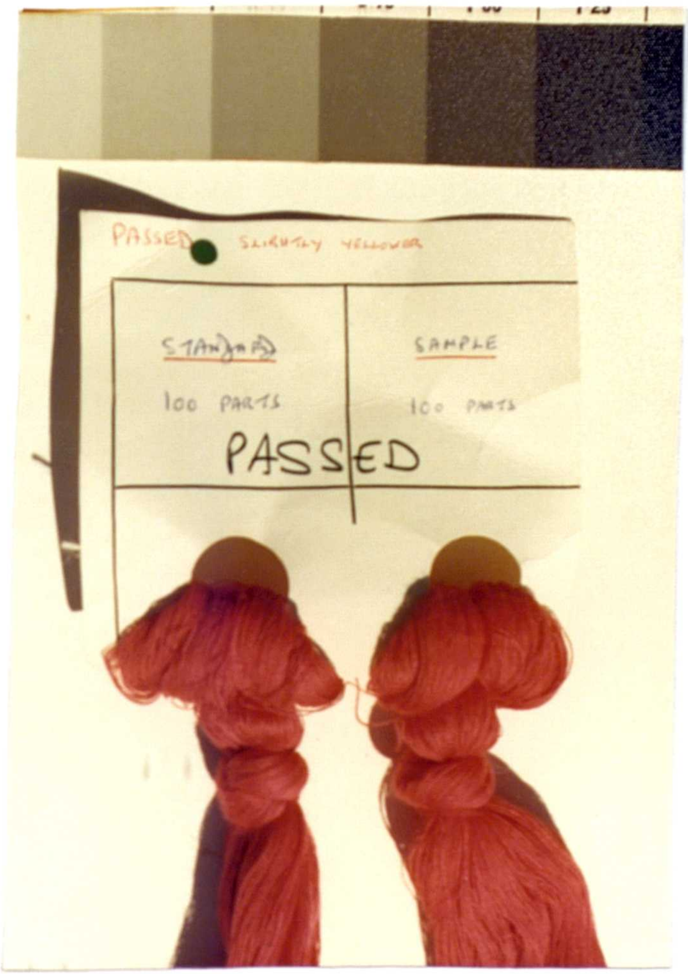


Weaving



Spinning
Mule

Textile amples



Samples of raw wool showing colour variation

Carpet Manufacture

Colour is obviously a very major aspect of the carpet manufacturing industry. Visual colour assessment is relied upon almost exclusively, and although the tolerances generally allowed are marginally bigger than in the textile industry[1] very fine colour differences must be detected in most stages of carpet production. The colour defective individual would be at a considerable disadvantage in this industry and mistakes made in the selection of coloured wools could cause considerable financial embarrassment to a manufacturer. Although one company reported that at least two hundred of the three hundred and fifty employees engaged in colour decisions, could make mistakes which would not be checked, it seems unlikely that a person with defective colour vision could, in fact, survive more than a few days before his anomaly was discovered.

As far as could be determined the pre-employment testing of colour vision seems to be a standard feature of this industry. The five companies who returned the questionnaire all used the Ishihara test. One company mentioned that because over three hundred different shades were used, and correct colour identification was necessary in all departments, the giving of a colour vision test was the first procedure at the initial interview

1. Opinion expressed by Mr. Gale, Wilton Royal Carpet Co.

In another large carpet factory the Ishihara test was introduced after the wrong shades of the colour pink had been selected for winding and weaving, and a fairly large quantity of faulty carpet resulted. The person responsible for the mistake was found to have defective colour vision when the company took medical advice. The man was transferred to a non-colour job, but because of the obvious limitations in a colour-orientated industry, he soon found alternative employment elsewhere. Since this mistake occurred in 1958, the company does not employ anyone in the factory "in any capacity" who fails the Ishihara test. Care is taken not to alarm individuals who fail by telling them that they are colour blind; they are told that they have failed the colour test and will need a certificate stating that they are not colour-blind if they are to be employed.

A company employing only eighty people on critical colour work, gave a colour vision test "during the training period only". If they had reason to believe that an individual's colour vision had deteriorated, they were sent to a doctor for a colour visbn test. This company reported occasional mistakes due to defective colour vision, which seems to indicate that perhaps not everyone received the test, or that it has only recently been introduced.

The Ishihara test seems to be fairly satisfactory for the purposes of screening employees for the carpet industry. The work involved requires a high degree of sensitivity to colours and the test ensures that only those with good colour discrimination pass. Visits weremade to two carpet manufacturers and both seemed pleased with the Ishihara test. However, one company visited also used a practical trade test which they had developed, similar in principle to the Holmgren wool test. Neither of the two companies were aware of tritan defects or acquired disturbances of colour vision and the failure of the Ishihara test to detect these aspects of abnormal colour vision; they were similarly ignorant of changes in normal colour vision with age.

The number of people involved in colour aspects varied according to the size of the company. One factory stated that three thousand, five hundred people were involved in critical colour work. All jobs involved some colour judgement and are listed below:

1. Design of carpets - choice of colours
2. Handling and sorting of raw materials.
3. Dyeing of raw materials
4. Winding of bobbins
5. Setting up of looms - selection of bobbins
6. Weaving
7. Inspection of finished goods for faults
8. Handsewing/mending of areas missed by machines
9. Quality Control personnel
10. Laboratory staff

11. Salesmen

12. Dispatch staff

A visit to the dyehouse of one large carpet manufacturing company revealed the extreme diversity of colours and the large number of very close shades used. Terms such as "red-black", "purple-black", Blue-black", and"black-black" were used, and an inspection of samples showed how small were the colour differences involved. A large variability in both whites and blacks is noticed. All surplus dyed wool is recycled and dyed black, and it is partly this policy which results in such a big diversity between the black wools. Small variations inevitably occur between samples of the same shade number of colour but different dye lots. Nylon materials pose particularly difficult problems maintaining a constant shade. Colourmatching is carried out under controlled illumination conditions in a special room using standard samples.

The chief dyer indicated that pale colours are slightly more difficult to match than dark colours, but greater tolerances are allowed for dark hues. Greys are particularly difficult to control. In one company visited, the maximum dye load serves for only five hundred y ards of carpet. If the material is earmarked for a plain carpet then single dyes (preferably of the same dye lot) only are used. This ensures that the colour remains uniform throughout. Occasionally slight colour differences may be noticed before weaving, usually because different dye lots are used; in this event a uniform affect is producted by interweaving sample 1 with sample 2.

Despite an "indefinite number of colours" used, few problems are reported, and disputes on the subject of colour arise only occasionally. In the company visited eight or twelve thousand bobbins and up to thirtytwo different coloured bobbins may be used on one loom. The setting up, and operation of a loom, is often carried out by one individual. Hence selection of the correct coloured bobbins from stock and the final manufacture of a length of carpet is the sole responsibility of one man. It is therefore easy to envisage the disasterous consequences of employing colour defective individuals. Re-dyeing of carpets can take place after manufacture if this is necessary, but it is usually more economical to sell faulty carpets at a discount price than to redye finished goods. One of the most arduous visual tasks, is the inspection of finished carpets and the insertion, by hand of one or two threads at appropriate places in slightly faulty carpet. The speed of mechanised manufacture frequently results in a whole line being missed by themachine and this is made good by female inspection workers. This calls for a very high degree of ability in the selection of the correct colour thread and detecting ofsmall colour differences in large lengths of carpet.

Dispatch staff are required to select finished goods from a warehouse store, often on the basis of written instructions which refer to a particular type and colour of carpet. This requires particular care when designs are produced in many different colours or shades and when specific quantities of carpet have to be cut before dispatch to the customer.

Thus visual colour assessment plays a part in almost every aspect of carpet manufacture.

ELECTRICAL INDUSTRY

Extensive use of colour coding in the electrical industries for cables and components puts the colour defective observer at a considerable risk, particularly in view of safety considerations.

The main processes and jobs involving visual colour judgement are:

1. Inspection of plastic colour finishes for cables.
2. Assembly of cable forms using differently coloured wires - rack wire men and cable joiners.
3. Electrical switch panel assemblers.
4. Telephone exchange assemblers/installers.
5. Assessment of colour T.V. equipment and T.V. chassis assemblers.
6. Production workers concerned with selecting, painting and inspecting colour-coded resistors and capacitors.
7. Assembly of circuit boards using colour coded components.

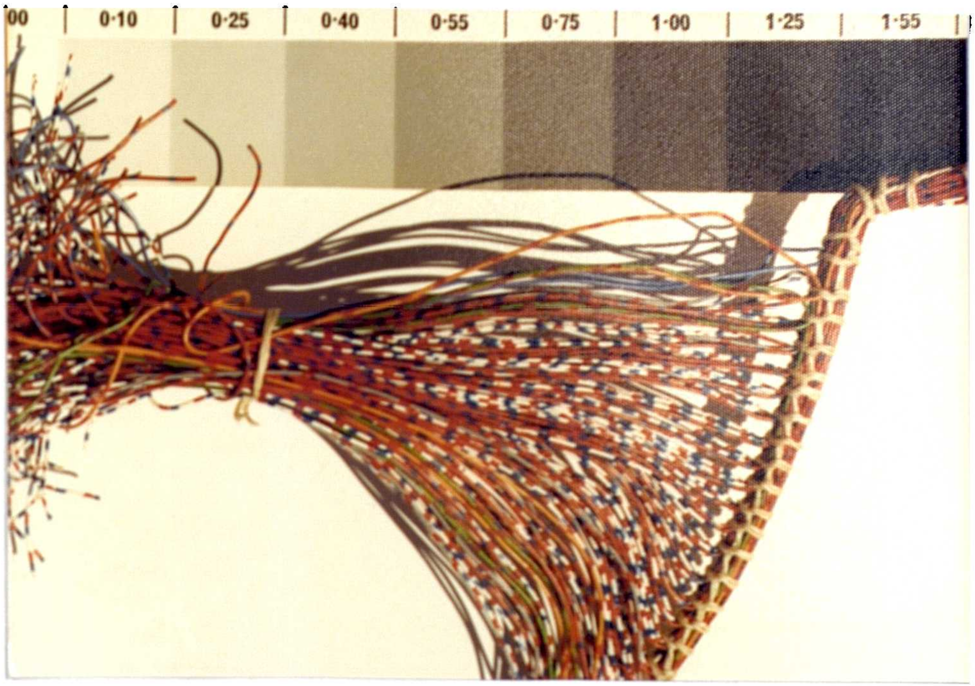
Very often colour naming is involved and this poses particular difficulties for the colour defective individual e.g. tasks involving the joining up of a red wire to a space marked "red" on a circuit board, or using numbers i.e. red to 3, blue to 4.

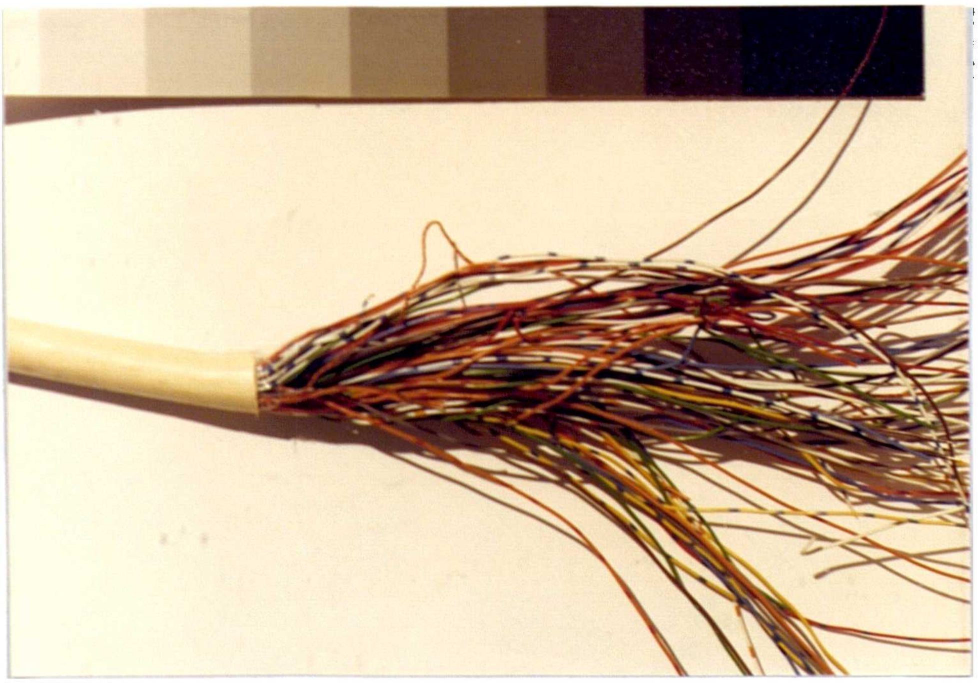
In addition, thousands of persons concerned with electrical appliances in their daily work e.g. electricians and engineers ofall varieties, are confronted with colour-coding. There is no doubt that many in these additional groups have defective colour vision.

Investigations made by the Committee of the Physical Society responsible for the 1946 Report on Defective Colour Vision in Industry demonstrated that very few colour defective individuals were in fact employed in the electrical industries. This view was supported by several electrical manufacturers contacted during the present study e.g. one large company (E.M.I.) who used the Ishihara test, generally found only two percent of failures. This may be accounted for by the large number of women operatives engaged in the industry as the Report suggests, and this study confirms, and by a certain degree of self-selection initially. Boys who discover their colour deficiency early frequently tend to avoid colour-orientated careers unless they are very determined. The determined few are usually those who make the higher grades of the industry on the basis of their academic qualifications and can often rely on objective measurements (e.g. for determining resistance/capacitance) or a second opinion. A number of deuteranopic observers who cope adequately in this way have been encountered.

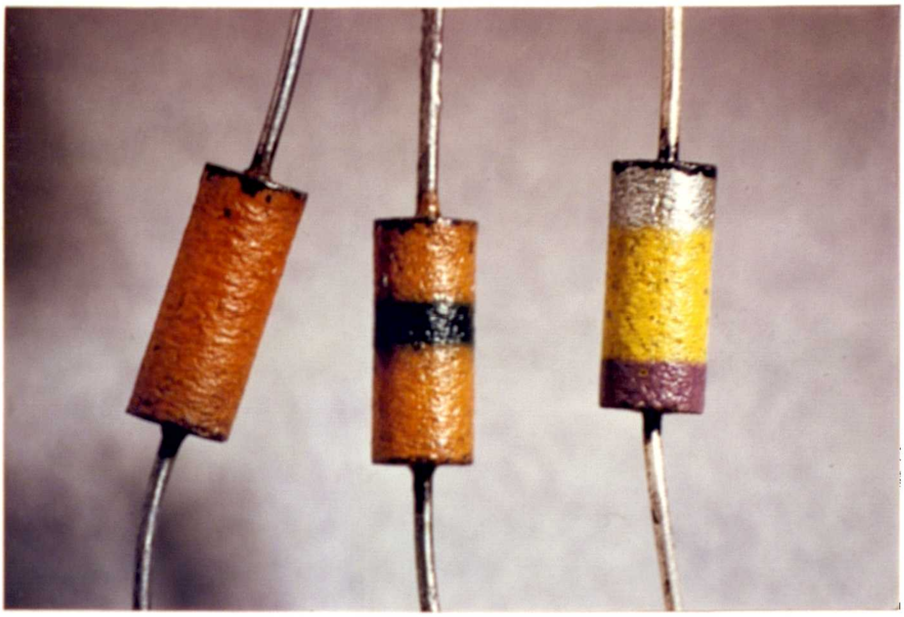
The 1946 Report further suggests that alternative employment, not dependent on colour judgement is usually available to the small numbers of colour defectives who are unable to cope with colour work in the industry; there is no reason to believe that this is not the case today. Several contacts mentioned that few outright rejections of candidates were

Electrical Samples





Colour-coded resistors



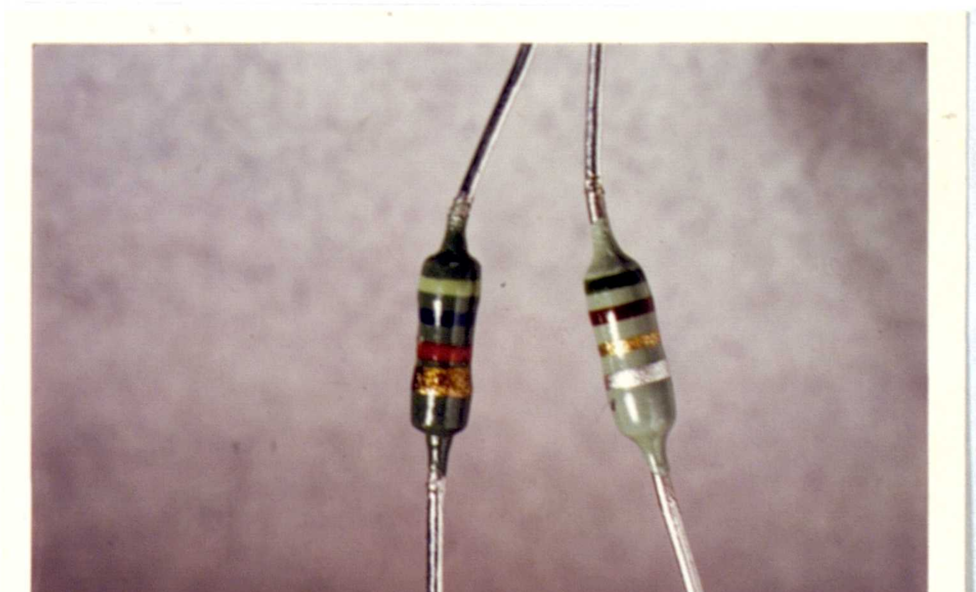
Old Samples

New Samples

Samples showing variation in band spacing

Colour-coded resistors

Use of white for background



These resistors show the necessary variation in band colour (green band) which results from use of a green coloured background.

made on the basis of poor colour discrimination because alternative work is available e.g. E.M.I. and G.P.O. Training Schools.

These observerations, however, do not wholly justify the failure to test for defective colour vision by the majority of electrical manufacturers who supplied information to the Committee in the early 1940's. The situation is considerably imp roved today, but colour vision testing is far from universal , in practice. Of the sixteen companies who completed the questionnaire, eight gave a colour vision test, four did not and four gave no information. A resistor company, employing two hundred people on colour work asked in a medical questionnaire if the applicant had ever had a colour vision test - they found that ninety-five percent had been tested. Comments such as this one, from a large cable manufacturer, summarises the attitude taken in many companies:

> "The ability to distinguish colours affects about half of our eight hundred employees, but apart from us asking each individual when he or she joins the company whether they are able to distinguish colours, I cannot say that we give them a test."

Frequently large numbers of people within a single company may need to interpret colours. In one cable factory, one thousand two hundred employees were involved in colour identification; another mentioned five hundred maintenance, production, technical and quality control staff. Both these companies used the Ishihara test.

The use of trade tests e.g. pairing up of coloured wires, naming coloured wires, naming the coloured bands on colour-coded resistors, is common in the electrical industry. This practice was noted in the 1946 Report on Defective Colour Vision in Industry with the comment that little care seemed to be taken to produce samples which would be used in practice i.e. dirty samples or under the conditions of use (often torch-light underground). This point was raised with one manufacturer who used a trade test, and had also appeared to have been overlooked. Two companies who provided additional information/comments in the questionnaire and as a result of personal visits to the factories, indicated dissatisfaction with the Ishihara test and a strong preference for trade tests. One found the Ishihara test "too severe". There is no doubt that many anomalous trichromats can cope with cable identification and a trade test does therefore seem to be more appropriate in some cases.

A number of mistakes resulting from colour vision defects, were reported. A large well-known cable company, who did not test colour vision, reported the case of a colour defective apprentice electrician who had joined a positive lead to the earth terminal during the fitting of a domestic appliance.

A company of international fame, who manufacture colour-coded capacitors, reported that a large quantity of capacitors had been spoilt, four years ago because the wrong coloured stripes had been applied to the components by a colour defective operator. The mistake alerted the company to the need for colour vision testing and the Ishihara test was introducted. A visit was made to see the procedures involved. Two men are responsible for selecting the paint which is purchased from paint manufacturers. Grey paints are prepared by these operators on a trial-and-error basis of mixing black and white paints, but no other colour mixing is done on the site unless supplies run low. No attempts are made to control the shades used and variations in colours, particularly brown, grey and orange are common and accepted as "inevitable". Thirty-six women, working twelve at a time in three shifts, are responsible to select and change the paints as required. Since the operators work entirely independently it is easy to see how the mistake quoted arose. Five dippings take place to produce the five different coloured stripes. Twenty men are engaged in inspection work noting in particular the colour-codes used. It is estimated that one man inspects six thousand colour-coded capacitors an hour.

A visit was also made to a large factory engaged in the production of colour-coded resistors. In this case many of the operators are men, and normal colour vision is essential. Little care is taken to ensure the reproduc ability of paint colours. Operators are given instructions which indicate the colours of bands to be painted onto the resistors e.g. a card displaying instructions

600 red
red
green
gold

The operator obtains suitable quantities of the paint colours required from the paint room and sets up the machine with small baths of the appropriate colours in the correct positions. At this point the work is checked by a forewoman to avoid possible mistakes. Discussions with the forewoman revealed several cases of confusions between grey and green which had taken place, but in her many years of experience, she was not aware of any gross confusions between colours. This seemed surprising because it was not the company policy to test the colour vision of employees. A knife edge arrangement situated in the paint baths ensures that the correct thickness of paint is applied to the resistors as they are pulled along the machine by the operator.

Post Office

During the early part of this study, contact wasmade with the G.P.O. Psychological Services Branch who were at that time, reviewing the colour vision requirements among apprentices

- engineers and telephonists. There is no standardisation of colour vision testing within the G.P.O. and at present trade tests seem to predominate for engineers. The possibility of introducing a colour vision test for switchboard telephonists has also been considered. These operators rely on colour coding for certain switches e.g. the 999 emergency call button is colour-coded, but as it islocated separately from the standard controls other factors are involved for recognition purposes). No test is given at present to this group. Throughout the eleven G.P.O. areas in the U.K. almost one thousand apprentice engineers/technicians are recruited each year. Two areas are known to use the Ishihara test. Others may use trade tests or paint charts for colour identification tests, but a standardised procedure is obviously needed.

In addition, much of the routine work is done by outside contractors and no attempt is made at present to screen this group for defective colour vision. The case of a colour defective contracted electrician who had wired a large circuit incorrectly was reported. A visit was made to the local G.P.O. Training Centre to view the wiring tasks involved in telephone installation and exchanges.

Electricity Boards

Enquiries were made within the Electricity Council concerning the testing of colour vision among employees of The Regional

Electricity Boards. The Electricity Council co-ordinates the activities of the twelve area boards in England and Wales and the two Scottish Electricity Boards. No national policy for colour vision testing exists because the subject has never caused problems, but questionnaires circulated to the medical officers of the Regional Boards reveal a positive attitude towards the subject. The four who replied all used the Ishihara test. Numbers involved in the different groups who provided this data are given below:

1. South Wales Region	1,000 Electricians and fitters
2. North West Region	1,000 Engineers 2,000 Industrial Staff

The South East Board give the Ishihara test to apprentices and the London Electricity Board are considering the form of colour vision testing to be introduced for control engineers working a new fourteen colour display/transmission systems. for controlling

<u>Gas Boards</u>

Gas fitters and electricians working for the Regional Gas Boards frequently need to identify colour-coded cables. Seven of the twelve regional boards of the British Gas Corporation returned the questionnaire indicating the persons concerned with colour identification and the colour vision testing policies.

A summary of the information received is given below:

1. North East Region

Keystone visual screener, and if necessary, Ishihara test given to approximately 1,050 new gas fitters, maintenance men and vehicle drivers.

2. Southern Region

Ishihara test given to 74 telecom circuit designers and 1,260 gas fitters/electricians.

3. North Thames Region

Colour matching test and/or Ishihara test given to apprentice electricians (5 - 10 a year) and gas fitters (40 - 50 a year).

4. Welsh Region

Ishihara test given

5. Scottish Region

Keystone and Ishihara tests given to 1,500 electricians and 100 operators in control rooms at Gas Production Stations.

6. North West Region

Ishihara test and wire identification test given to all new gas fitting apprentices (605) and electricians(14).

7. East Midland Region

Ishihara test or Keystone test given to 5 electricians, 135 Drivers and 250 Gas Fitting apprentices.

One comment worthy of note indicated that

> "the degree of colour discrimination required needs such accurate judgement that normal colour vision is essential."

It was pleasing to find such widespread testing of colour vision and awareness of the potential hazards that would result from the employment of colour defective individuals.

History of colour coding for electronic components

Extensive enquiries were made in an effort to investigate the history of colour coding and in particular how the choice of colours was made, and whether the problems of colour defective individuals were considered. Difficulties were encountered because the system was evolved during the 1930's and it was not possible to trace any documents on the subject. Few individuals concerned with the original specifications were still active in the field, and those who might have been expected to provide valuable information were not familiar with the historical background.

Correspondence with a number of National electrical and electronic organisations and the British Standards Institution (B.S.I.) provided most of the information.

The colour code for resistors and capacitors employing the use of ten colours (black, white, grey, red, orange, brown, yellow, green, blue, violet)*originated probably in the 1930's[1]. and was based on numerical values being allocated in the same order as the colours occurred in the spectrum, with the addition of black, brown, white and grey. Colours were used because resistance and tolerance values can be indicated in a small space using four bands.

* as set out in B.S. 1852

1. Personal written communication with Mr. D.P. Doo, Technical Secretary, The British Radio Equipment Manufacturers' Assoc. 3rd September 1975
   Personal Oral communication with Mr. A.W. Pittard, Technical Officer B.S.I.

The colours are specified closely in B.S. 381C. It appears that no thought or attention was given to the troubles arising from defective colour vision when the code was written[1,2,3,4], partly because the need to represent each of the numbers 0 to 9 by a clearly defined and identifiable colour left little freedom of choice. One source[3] considered that"brown was perhaps not a good choice, but was more or less inevitable". Although direct efforts were not made to consider the colour defective BSI[4] were anxious to stress that this subject had not been ignored or dismissed by those parts of industry which have formed the committees responsible for these standards. But no evidence that this is in fact the case could be given. The writer[4] indicated that during seven years of work at BSI this was the first query that he knew of which questioned the relationship between colour coding and colour vision defects. He admitted that the problem was not one which was at the forefront of committee members' minds. The colours were chosen by considerations of the ease of manufacture, and the necessity to use colours which contrasted well when they were adjacent[4]. In addition, factors such as convenience during manufacture, suitability for the purpose and stability of colour are all factors which have had to be taken into account.[4] One source[3]

2. Personal Communication, written, with Mr. J.A. Stephens, Technical Officer B.S.I. 19th September 1975

3. Personal written communication with Mr. K.J. Coppin Education officer, Institution of Electronic and Radio Engineers, 4th September 1975

4. Personal written communication with Mr. G.A. Raley, Senior Technical Officer B.S.I. 24th September 1975.

stressed that the difficulties associated with colour control e.g. fading and discolouration with age, elevated temperatures etc., which are experienced at present, would still have given trouble to the colour defective. The influence that the nature and finish of the surface (e.g. matt or gloss finish) has on colour identification, would also have caused problems for the colour defective. One author[4] pointed out that in fact major difficulties in colour identification only arise when one is confronted with assorted components from different suppliers.

A number code was used prior to the introduction of colour, but this poses other problems, in particular the difficulty of reading the value of the component at any orientation. Attempts have been made internationally to develop a numerical system which is not dependent on colour and an ex-technical officer at B.S.I.[5] feels that this system may gain more widespread use than the colour code in time.

Considerations on the Tolerance/Background Specification

Additional potential problems arise because despite the careful specification of the colours used in the British Standard Code (in Munsell notation and the C.I.E. x.y. co-ordinates) no tolerance limits are given. This is

5. Dr. G.D. Reynolds. Personal Written Communication 21st October, 1975.

partly because , in practice, adherence to the code is only approximate, as visits to the manufacturers revealed, and the code is only a recommendation and cannot be legally enforced. Specifying tight tolerances is probably useless when so many factors influence the overall colour appearance during the manufacture and life of the component (e.g. variation in pigments used due to availability and different source of origins, temperature during the manufacture, fading, soiling etc.). However, the failure to specify tolerance limits leaves the situation open to a certain degree of abuse by manufacturers as the comment quoted from reference 4 indicates. Attempts have been made to avoid deep reds, dark greens and dark browns[5] although no details are known. The electronic Industry Association in the USA[5] define the colours using the Munsell system giving limits of hue and saturation. These standard colours, without their tolerances, were adopted by the International Electro Technical Commission in Geneva as an international standard. They were translated into the hue and saturation system internationally recognised (since Munsell is not recognised) and some experts consider that the effect of the translation is to leave the colours inadequately defined.[5]

The situation is further complicated by a lack of specification of the colour of the background of resistors and capacitors. In the latter case a background colour is often not required because the coloured bands fill the entire body of the component, and this should be encouraged for resistors. Individual manufacturers are apparently free to select their own background colour[6] and in many cases this necessitates a slight alteration of the hues of the bands (see photographs) Often this involves a desaturation of the band. The use of a standard white background for resistors would eliminate this problem.

Recommendations

In summary, it appears that the following points could be recommended for resistors/capacitors:

1. Specification of background colour - white should be considered although this will reduce the number of band colours to 9. An alternative code to overcome this problem using a white background is suggested in Section IV.3 using colours which are not confused by colour defective observers.

2. Some attempt should be made to set tolerance limits for the colours of bands, and an effort made to secure the co-operation of manufacturers in controlling the colours used as far as is practically possible.

3. To maximise contrast effects the use of a glossy finish for the coloured bands should be encouraged. Some colour

6. Personal oral communication with Mr. Bageley, Erie Resistor Co., Great Yarmouth.

defective observers find resistors with a matt finish more difficult to recognise than those with a glossy coating.[7]

The application of a transparent coating to the finished resistor would reduce the soiling problem should a white background be introduced, and would also provide a glossy finish.

4. The use of fluorescent paints for the bands should be considered.

5. Colours which appear fairly de-saturated e.g. grey, blue and some violets and yellows,should have a high luminance value.

7. Noted in the 1946 Report on Defective Colour Vision in Industry

Colour-coding of cables and wires

Some efforts have been made over the last few years to take into account the problems that colour defective individuals have with colour-coded cables and wires. It seems surprising that the problems associated with capacitors and resistors should have been overlooked. Since the colour coding of a cable is used for identification purposes only and is therefore of more restricted colour use than the resistor where colour signifies a definite numerical value. However, objective methods are available for obtaining resistance and capacitance values, and it is not easy to replace the human observer for some wiring jobs.

Although B.S.I. are concerned with the compilation of standards for recommendations they do not determine the contents of a standard; that responsibility lies with industry.[1] It was therefore the various industrial organisations and professional bodies who co-ordinate the activities of industry who were approached for information in this study.

The Telecommunication Engineering and Manufacturing Association who have been closely involved in the colour-coding of cables and wires, indicated[2] that many factors have to be considered in the colour coding of cables. Considerable efforts have

1. Personal written communication from G.A. Raley, Senior Technical Officer B.S.I. 24th September 1975

2. Personal written communication from P. Sutton, Technical Secretary T.E.M.A. 8th September 1975.

been made to reduce the number of colours and the colour combinations to an absolute minimum; the colour combination agreed has to be a compromise between the ideal and the cost of manufacture and the tolerance which can be allowed before it becomes difficult to distinguish between wires, have to be considered.

The Electrical Cable Makers Confederation provided valuable background information[3] when a visit was made to their London office. The British Electrical and Allied Manufacturers Association[4] also assisted. Before 1939 the earth feed in the domestic wiring was coded brown. The three core code of black(neutral), red(live) and green(earth) was introduced because of the obvious associations. It appears that the potential difficulties that colour defective observers would experience with this code were not considered. Before the European standard of brown, blue and yellow/green stripes were introduced for flexi ble domestic wiring, Germany used red for the earth connection.

Recent Attempts to Consider the Colour Defectives

The Society of Dyers and Colourists raised the question of colour vision defects and colour coding of cables with the

3. Mr. M.H. Kelly, Technical Department E.C.M.C.
4. Personal Oral Communication with Mr. Reed B.E.A.M.A.

General Secretary of the Institution of Electrical Engineers in April 1968[5]. Mr. K. McLaren, who was at that time Chairman of the S.D.C. Colour Measurement Committee, suggested that confusion in the field of domestic wiring could be considerably reduced if the colours used were bright scarlet, black and blueish-green. The Society adopted this recommendation and proposed it to the I.E.E. asking for their observations on the suggestion.

The reply from the I.E.E.[6] explained that changes in the colour coding of British cables were pending, and the question was under consideration by the Wiring Regulations Committee, who would be informed of the Society's observations. The letter pointed out that although defective colour vision had received "considerable attention" in the international discussions on the subject, it was not possible to make a choice on this account alone. The major choice mentioned was the need to select a set of colours which were acceptable to all countries involved in the new standard and to exclude colours which had previous associations in particular countries. When this was done the only colours left were blue, black, brown and a combination of yellow/green(in stripes). The latter combination was adopted for the

5. Letter from Dr. M. Tordoff, General Secretary of the Society of Dyers and Colourists to the General Secretary Institution of Electrical Engineers 4th April 1968

6. Letter from D.C. Brice, General Secretary I.E.E. to Dr. M. Tordoff, S.D.C. 11th April 1968.

earthing conductor. McLaren took the selection of a yellow/green striped earth conductor further with the I.E.E. pointing out[7] that almost any pair of colours would cause less trouble than yellow and green - the obvious one being black and white and asking for details on how this choice was made. The reply[8] pointed out that although it was appreciated that yellow and green were not ideal colours, when all the various codings for the countries involved had been excluded,

> "green and yellow are unfortunately about all that is left".

McLaren could not rest. In further correspondence with the I.E.E.[9] he pointed out that since no country had used blue and white for a current - carrying conductor, he would have thought this would permit its use for an earthing cable. He nevertheless accepted the choice, but asked what steps were being taken to ensure that the particular shades of yellow and green which were to be chosen, were those least likely to be confused by colour defectives.

It appears from the apparent lack of further correspondence with the I.E.E. that McLaren was put onto B.S.I. concerning

7. Letter from Mr. McLaren S.D.C. to Mr. D.C. Brice, I.E.E. 24th June 1968

8. Letter from Mr. D.C. Brice I.E.E. to Mr. McLaren S.D.C. 26th June 1968

9. Letter from Mr. K. McLaren S.D.C. to Mr. D.C. Brice I.E.E. 1st July 1968

the draft revision of B.S. 2746 (1966) for colour coded cables. In a letter to Mr. R. Fanshawe[10] he expressed mild concern that the colours brown, light blue and green/yellow, which had been adopted for a new colour-coding system for domestic wiring, had been chosen from colours which had not been used before rather than because they were readily distinguishable by a colour defective. He said that it was still possible to minimise confusion by a careful choice of the particular shade of brown, blue and yellow and green and asked for assurance that this had in fact been done. Theoffer was again made to co-operate with B.S.I. to eliminate this hazard if the subject had been overlooked.

Enquiries were made among some of the colour defective observers who had taken part in the simulated industrial tasks for thisstudy to see whether or not any difficulty was experienced in identifying the old and new domestic wiring leads.

Eight deuteranomalous trichromats gave information; all were confident with the new colour-coding systems (green/yellow, brown and blue) and three had some difficulties with the old red, black and green wires particularly when they were soiled, and viewed in low illumination levels. Of

10. Letter from Mr. McLaren to Mr. R.H. Fanshawe, British Standards Institution, 20th August, 1968.

the three deuteranopes who gave information all found the new system easy and one was hesitant with the old colours.

The protan observers had slightly more trouble with the old system than the deut ans. The three protanopes who were consulted all found difficulty with the old red, black and green wires and frequently confused the red and green wires especially when they were soiled, the new coding caused them no trouble at all. Two of the four protanomalous observers who replied, reported no difficulties with either system; the other two were unable to use the old coding colours, but found the new colours easy to use. Of the eighteen colour defective observers consulted no-one reported difficulties with the green/yellow, brown and blue. From the colour defectives point of view the introduction of the new colours for domestic wiring is obviously a considerable improvement.

FOOD INDUSTRY

Critical colour matching is not often an important feature of this industry except in laboratories and quality control departments. Enquiries revealed that most production staff are only occasionally required to make important colour judgements. These are usually in the tasks of selecting or sorting ingredients and packaging finished products.

Most companies are now aware that careful colour control is necessary for good packages since it is often on the basis of the package colour that the customer judges the quality of the product and obtains a first impression; a faded carton may suggest old stock.

Thirty-five food and drink companies and three firms concerned with the manufacture of food colourants completed the questionnaire. No mistakes that could be attributed to defective colour vision were reported. About fifty percent of those who completed the questionnaire did not test the colour vision of prospective employees. In general, these were the companies who considered good colour vision to be relatively unimportant. Those companies who tested colour vision routinely used the Ishihara test which was administered by the company Medical officer or nurse or the Quality Control staff.

Although perfect colour vision is probably not essential for many jobs outside the Quality Control and testing laboratories in this industry, a general awareness of the basic colours is important for most employees. Some companies are obviously at risk because a colour vision test is not given. One of these is a large food colourant company who reported that two hundred people were involved in colour work but these are not given a colour vision test. Three out of four branches of one of the major biscuit manufacturers in the U.K. reported that they did not test for colour vision despite the need for good colour discrimination in some departments - mamely the selection and sorting of ingredients.

Only one questionnaire was returned from a bottled drink manufacturers. This major company did not give a colour vision test to staff although they mentioned that the correct identification of bottle colours (amber and green glass) was necessary. Presumably the correct colour of bottled and canned drinks is an important consideration too. Investigations were also made in the brewing industry. The need for correct specification and standardisation of beer colour led to the development of the Lovibond Subjective colorimeter by the brewer, Joseph Lovibond, in 1878. He realised the need for a standard beer colour and noted several brown glass windows in Salisbury Cathedral which approximated to the ideal beer colour. This led him to obtain a range of brown glasses and eventually to abandon his brewing for the manufacture of the Lovibond tintometer glasses which are now used for industrial purposes all over the world, in the form of Lovibond Tintometer colorimeter. It was surprising, therefore, to find that colour vision was stated as playing only a minor role in two out of three major breweries who completed the questionnaire. One mentioned that

> "colour vision is not significant in our industry and consequently there is no need for employees to be screened."

and another

> "There are no jobs in our industry where colour plays a major role and where we demand a high standard of colour vision. A colour vision defect has never resulted in non-acceptance for an appointment."

The one company who stated that visual colour judgements were made by eight people in the laboratory for the control of beer colours also indicated that colour played only a minor role in their operations, and no colour vision test was given. Further enquiries with Tintometer Limited[1] revealed that many of their visual colorimeters are indeed sold to the food and drink industries, including breweries, and the Scottish Whisky industry. It seems likely that visual colour judgement does play a significant part in brewing and the information contained in the questionnaires was not representative of the industry.

1. Personal telephone conversation with Mr. Smith Tintometer Limited 8th July 1976.

The colour of vegetable, mineral and animal oils plays a major role in determining the quality of these products and most countries now have standard colour specification for oils. In a lecture to the Colour Group of Great Britain (Newton Lecture 1970) entitled "What use is colorimetry?" G.J. Chamberlain of Tintometer Limited recalled a case where a tanker had docked with a major cargo of whale oil and a dispute arose as to the cash value, which hinged on colour. Mr. Chamberlain was asked to adjudicate and he remembers that

> "a fortune depended on which side of the line I placed the colour."

In the USA, Canada and Australia there are a number of provincial and state laws concerning the colour of oleomargarine. A maximum colour is specified which will prevent confusion with butter, and any increase in colour is penalised by the levying of a duty, expressed on a sliding scale, which increases with colour. Mr. Chamberlain further remarked in his lecture that some countries hold enforceable colour standards which insist that the good name of the country shall not be prejudiced by the export of bad-coloured products. Such standards exist for Malaysian pineapple, Californian peaches, citrus juicer from Chile and Australian honey. A colorimetric chemical test, involving legal force, can separate unpasteurised milk from pasteurised milk.

Visits were made to seven large food companies to assess the role of visual colour discrimination in the manufacturing and

and chemical processes. Although colour is a significant factor, particularly as this largely determines the initial customer acceptance of a product, most companies considered flavour to be more important.

A number of factors affect the final colour of a foodstuff and often these are controlled very little during the manufacturing process. The fat distribution of some products is one such variable and the temperature of cooking affects the final food colour. Oxidation may often change the colour of a foodstuff, chocolate, for instance, tends to redden with age. These factors must be taken into consideration during manufacture.

Colours of fruit-centres, chocolate and caramel are important in the confectionery industry. The manufacturer may restrict the purchase of raw materials e.g. cocoa beans, to one country or area in order to ensure the minimum of colour variability initially. One large chocolate manufacturer indicated that although colour standards are held for caramelised sugar, glucose and dextrose, it is impossible to hold such a standard for chocolate because there are so many variables and no instrument is available to measure all the necessary qualities. Quality control therefore depends very much on the experience of personnel. In one company visited, one man was responsible for the selection of a new standard product for each day and visual assessments were made by other staff to this one reference standard.

Technical and Quality Control personnel in some food companies visited have concluded that the Ishihara test is too sensitive for their purposes. To allow for this some individuals making up to three errors in the test have been "passed". Others have produced their own trade tests to assess the practical ability of a prospective employee, for instance, one large confectionery manufacturer asked individuals to identify the colours of a selection of sweet wrappers in cases of doubt. If the individual failed the Ishihara test, but passed this trade test, he was not barred from employment. Another major food company used a set of coloured pencils and asked for colour names. Yet another devised a trade test of vegetable oils for certain groups who worked with these products. Considerable ignorance of other standard clinical tests for examining colour vision, apart from the universally known Ishihara test, was displayed. It is very evident that guidance in this area is obviously needed.

Manufacturers stressed the importance of colour in packaging Often they appeared more concerned about the colour control of cartons than the colour control of the food product! Standard packages are usually kept including examples of light and dark extremes to indicate the colour tolerances involved.

The Meat Research Institute mentioned the considerable role that colour plays in the family butcher business. Colour is a major factor in the selection of fresh meats by the customer. Often little care is taken to ensure adequate or suitable illumination which might affect the colour of meat advantageously.

The experiences of an ex-Medical officer of a large confectionery group were recounted in a letter and are worth noting:

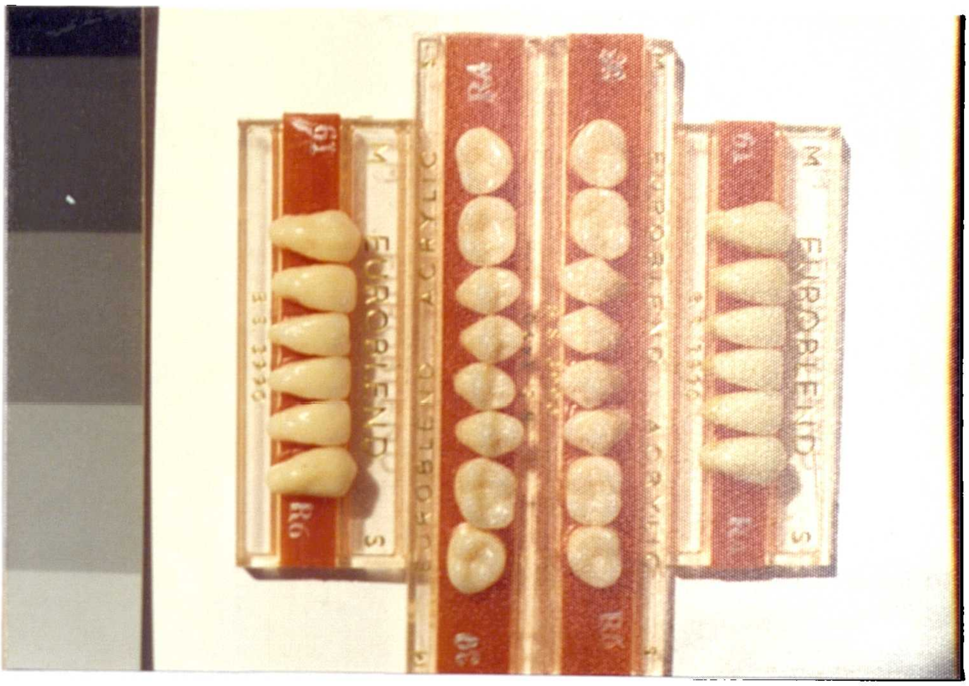
> "One of the foremen complained to me about two men in the fruit gum packing department, whom he said were "quite useless" as they would insist in putting green gums into the machine instead of red ones. After this I tested all new recruits for that work and after a few weeks I had rejected almost 10% of the applicants. I subsequently subjected <u>all</u> new employees to the Ishihara test as I found so many jobs depended on correct colour vision - <u>electricians</u>, <u>advertising men</u>, <u>store-keepers who handle coloured paper and ribbons</u> - even <u>firemen</u> who used canisters of different colours for the breathing apparatus for various fumes."

The extensive role that colour judgement plays in the selection of some raw materials was also pointed out. Buyers of cocoa depend almost entirely on the visual colour assessment for their choice of cocoa beans, and it is possible that very considerable financial losses could be incurred by companies who employ colour defective buyers. As the ex-Medical officer noted:

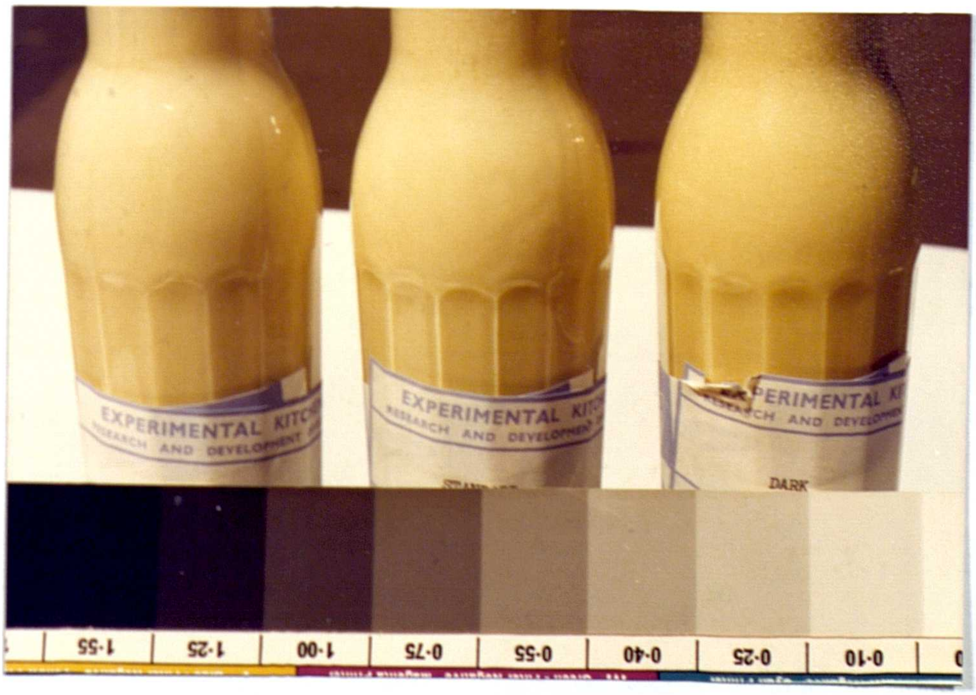
Buyers

"Cocoa buyers in all areas judge the quality of the fermented beans by colour. I found that I could sort a pile of the beans into five or six groups of varying shades, but the colour defectives could only make two or at the most three groups. On more than one occasion I found a potential buyer to be colour blind. I remember turning one man down that the Company wanted and they didn't like it a bit, but they had to agree with my decision when I demonstrated how bad his choice would be."

Miscellaneous samples



Dental surgeons rely heavily on colour discrimination for the matching of dentures and crowned teeth



Colour control is an important feature of the food industry.
The centre sample is the standard ideal colour, the sample to the left is too light and the sample to the right is too dark.

FURNITURE INDUSTRY

Widespread ignorance of the possible problems, and indeed financial losses, that might result from the employment of colour defective individuals in this industry, was revealed in the information contained in the questionnaires returned by four furniture and upholstery manufacturers. In all cases no colour vision test is given despite several categories of job relying heavily on the correct identification of colours. The Furniture Industry Research Association (F.I.R.A.) indicated that the main activity requiring visual colour discrimination and identification within the industry was in the matching of upholstery fabrics for colour. It was thought that many companies did this on "an informal basis usually without the right conditions" (possibly a reference to lighting conditions?) and that many people in different places and at different production stages would be involved. The following situations, involving colour judgement, were mentioned:

1. The material store - store keeper may check deliveries.
2. The laying/cutting table - cutters see several rolls at a time.
3. The sewing rooms - operators join pieces together from different rolls.
4. General supervisors.

The four manufacturers contacted confirmed this information In one company forty people are concerned with the cutting and matching of fabrics for upholstery.

The matching of wood grains poses similar problems. One company mentioned that colour discrimination was necessary for "spray polish colouring" and matching of timber before assembly for grain and colour.

At F.I.R.A. a total of twelve people are employed who are expected to exercise colour judgement routinely. This work involves comparisons of fabric samples with standards, in particular for the assessment of colour fastness and soiling. Two people in the chemical laboratory are also required to have good colour discrimination. No tests are used to check the colour vision of these people "unless circumstances suggest defects". They justify this by indicating that people in these positions have had long experience in colour work. But they are aware that ageing affects colour judgement.

The Timber Research and Development Association also completed a questionnaire. They indicated that colour did not play a significant role because they are a Research Association and only two finishers and three people involved in producing T.V. films require good colour discrimination. No colour vision test is given in this organisation.

None of the companies contacted was able to quote instances of mistakes which had been made due to inability to see colours correctly. Undoubtably colour defective individuals are employed in this industry and it is likely that only when mistakes or disputes arise over colour will thought be given to the possible introduction of a colour vision screening test. This state of affairs is to be regretted, but it seems inevitable.

GRADING OF GEMS

(with particular reference to diamonds)

Visual colour assessment plays a very significant role in the grading of cut and uncut (to a lesser extent) diamonds, emeralds, rubies and sapphires, and a large number of other gemstones. It is estimated[1] that up to one hundred thousand people are involved in the colour grading and assessment of gemstones, including diamonds, in the U.K. This number includes approximately five thousand individuals in jewellers shops assuming that atleast one person is responsible for the grading of gems by visual analysis in each shop. The rest includes those involved in dealing, buying, cutting, polishing and grading of gems.

Diamonds

Diamonds account for well over ninety percent of the total value of the world's trade in gems, and since it is in this area that the most significant colour mistakes are likely to occur, a special study was made of the colour requirements within the diamond trade.

Although spectrophotometric methods have recently been

1. Personnel communication with Dr. K.F. Burr, Diamond Grading Laboratories Ltds. Hatton Garden - July 14th 1976.

introduced in the diamond trade, the subjective element continues to play the most significant role in the grading task, and will continue to do so. Agreement has recently been reached within the E.E.C. to set up some form of standardisation for diamond colours, using master stones to be held in each country, and supplemented by spectrophotometric data. Since a price difference of between ten and twenty percent is usually involved in setting the grade of a diamond in one bracket rather than the next, the responsibility of the diamond grader and the demands on his ability to detect very small colour differences, cannot be over-emphasized.

A visit was made to the Diamond Grading Laboratories at London's Hatton Garden to see diamond graders at work, to discuss the role that colour plays in the grading procedure, and to view some of the colour differences involved.

The extremely critical nature of the work and the considerable dependence on human colour judgement makes the job of a diamond grader one of the most exacting of all the industrial examples seen. Thus it can be said that of all industrial occupations, the job of a diamond grader calls for the highest degree of sensitivity to colours. Following on from this it would appear that the employment of an individual with defective colour vision would impose a very considerable potential hazard, at least in the financial sense.

It is therefore surprising that no evidence of colour vision testing among those engaged in the diamond trade could be established. Extreme difficulty was experienced in obtaining the co-operation of those involved in the diamond trade, except for the Diamond Grading Ltd. in Hatton Garden. Letters and questionnaires were sent on several occasions to the two main groups involved - the Diamond Club and the Diamond Bourse, both in Hatton Garden. The Diamond Grading Laboratory provided most of the information for this study and indicated that they were not aware of the use of a colour vision test in any part of the industry[1]. They had only recently considered the necessity for good colour vision in diamond graders and therefore welcomed the contact with the present writer. As a result of the contact the principal graders of the laboratory attended The City University for a thorough ophthalmic investigation including colour vision tests - the Ishihara plates and the 100 Hue test. All performed well at the latter colour discrimination test and in many cases no errors at all were made.

One of the world's leading gemologists (a British man) who has deuteranopic vision described to the present writer the difficulties he has experienced with pink and pale green stones particularly when they are very small. He is unable to grade many stones visually, in particular diamonds, but has overcome his defect by concentrating on the physical/scientific side of the subject and does not consider his colour vision defect to be much of a handicap for him.

Colour characteristics of diamonds

The most valuable diamond is colourless, but generally small traces of colour are seen due to absorption effects and impurities. Five groups of diamonds are identified: Blue-white, green, yellow, brown, and red.
Green diamonds are rare and red varieties are extremely rare. Admixtures occur particularly between the yellows and browns and occasionally between greens and yellows. Yellow traces are identified in ninety percent of diamonds. The blueeffect in the blue-white or "water-white" gem is due to fluorescence; these are the most precious group of diamonds forming the highest grade.

Grading is usually done by a comparison with the master stone or standard of known colour and value, under a daylight source Nine or ten grades exist, and there is usually a ten to twenty percent difference in price between one grade and the next. The procedure adopted by the Diamond Grading Laboratory Ltd. is to compare a sample diamond with a set of nine or ten master stones placing it at different positions in the scale or arrangement, as well as direct comparisons with individual master stones.

Well-cut colourless Zircon gems suitably mounted and offered in poor light "to a plausible client" have often deceived even themost experienced pawnbroker. Manmade "YAG" and strontium titanate are also very similar in appearance to diamonds. The ability to distinguish and identify the characteristics of diamonds by visual means is of great importance.

Colour characteristtics of gemstones other than diamonds

After diamonds, rubies and sapphires are the most important precious stones from a commercial standpoint. Telephone conversations with a number of experts in gemstones[1] provided valuable information on the role of colour discrimination in the grading and valuation of gems other than diamonds.

Minerals are either idiochromatic (self-coloured) e.g. copper in malachite or more commonly allochromatic where the colour is due to impurities or trace elements e.g. topaz, spinel. Visual colour assessment is relied upon exclusively for the grading of most of these stones, and colour is considered to be the most important feature. Emeralds, sapphires and rubies show the greatest range in colour and command the highest prices. The most predominant colours are greens, reds and blues. Frequently the colour of a stone is related to the area of origin e.g. Burma rubies are a purple-red, Siamese rubies are a brown-red and rubies from Ceylon are more true red in colour,

1. Eric Brutom, gemologist, Editor of Retail Jeweller and Alan Hodgkinson, consultant gemologist and member of the Diamond Bourse.

often pink.

A list of some of the gems found in different colour groups is given below:

<u>Red Stones</u>

Rubies	Red zircon
Red spinel	Pyrope garnet
Pink Topaz	Almandine garnet

Red tourmaline

<u>Orange stones</u>

Some opals

<u>Yellow stones</u>

Yellow zircon	Yellow orthoclase
Yellow sapphire	Yellow spodumere
Yellow chrysoberl	Yellow apartite

<u>Green stones</u>

Emerald	Chrysoprase
Alexandrite	Sinhalite
Jadeite	Peridot
Sapphire	Chromediopside enstatite

<u>Blue stones</u>

Sapphire	Zircon
Blue spinel	Zoisuite
Cobalt glass	Aquamarine
Apatite	Turquoise
Tourmaline	Iolite

<u>Pink</u>

Sapphire

In a leading textbook on gemstones it is noted that it is extremely difficult for the eye to distinguish between pink topaz, tourmaline, mauve spinel, pale amethyst, kunzite and pink beryl.

Filters are frequently used by gemologists to reveal underlying differences in colour, and are particularly successful for discriminating between emeralds and its imitations.

Discussions with the Editor of the journal "Retail Jeweller" indicated that colour vision testing is not carried out in this branch of the industry either. Efforts must bemade to impress upon all those concerned with jemstones, in whatever capacity, the necessity of good colour vision.

GLASS INDUSTRY

Three glass manufactuers were contacted to establish whether or not critical colour discrimination is required in this industry. In general, it appears that few people are involved in very fine colour decisions, but considerable numbers must be aware of colour differences.

Quality control workers and production staff concerned with sorting and inspection of finished products probably have to exercise the finest judgement. Thismay involve large numbers - in one company over four hundred people are employed as inspection workers. The majority of these would be women and the incidence of colour vision defects in this group is much smaller than a similar male group. Furnacemen and batchmen and some other production staff are also concerned with obvious colour judgements. In addition electricians and plant maintenance workers (which total a hundred in one company) and those involved in transport (vehicle drivers) are also affected.

Correspondence with the British Glass Industry Research Association revealed that there is no special National policy concerning the testing of colour vision - individual companies make their own independent arrangements.

HEAVY METAL INDUSTRY/METALLURGY

Colour coding is used quite extensively for the identification of pipelines (B.S. 1710 (1971) and B.S. 349 (1973)) and this industry is an example of an area where familiarity with such codes is necessary. In addition, a colour-coding system often applies to the identification of steel (FORD AND JENKIN (1964)).

A number of processes in the production of steel and other metals also use colour judgement, but these may be superce ded by instrumental methods in the near future.

Before the advent of industrial pyrometers the temperature of steel was estimated or determined largely by the subjective colour assessment.

The Human Factors Group of the British Steel Corporation Corporate Engineering Laboratory proved to be concerned with the visual demands of personnel engaged in monitoring the production of steel with computer-linked visual displays. This group gave helpful information on the role of colour and the colour vision requirements in the steel industry.

Discussion with a member of the Mechanical Engineering department at The City University revealed that colour plays a significant role in colorimetric analysis and in metallography in certain industries belonging to this group. Identifying small colour differences and colour traces in certain metals, including steel, is of considerable importance for analysis. Colour plays a significant role in the metallurgic examination of materials under the microscope. The colours involved are often pinks, browns, oranges, yellows and greys. Inspection procedures rely heavily on colour clues for defects and inclusions in stock and colour is still one of the most important criterion for grading steel. Usually a judgement is made visually. Colour identification is also important in the grading and analysis of aluminium compounds.

Eight companies concerned with the manufacture of heavy metals, in particular steel, completed the questionnaire. Four of these mentioned only electrical work as being relevant to colour identification. One cited the occasion when an electrician, employed prior to the establishment of routine colour vision screening, connected wrong electrical leads, but no further details were supplied. It appears that the majority of steel manufacturers do not give a colour vision test to their staff. In one company where the Ishihara test was routinely used for screening, four hundred employees made some form of colour identification decision in their daily work. This included furnacemen (50), Painters (10) Spark testers (10) weighmen (20) and Crane Drivers (300).

The one aluminium company who returned the questionnaire did not give a colour test. They appeared to consider it unnecessary judging by their comment:

"Men do not work in isolation and mistakes would therefore be covered."

A nickel company described only elctricians, instrument mechanics, drivers and laboratory technicians as being involved in colour identification. They did not give a colour vision test to employees.

Metallurgists are a group who frequently exercise colour judgement in their daily work, particularly when undertaking microscopical analysis. The 1946 report on Defective Colour Vision in Industry recognised the possible difficulties for colour defective metallurgists, but considered them to be more of a nuisance than a definite handicap or bar to this type of work.

HORTICULTURE AND AGRICULTURE

Investigations in these occupations have been limited because they do not fall strictly within the industrial confines of this study. However, a number of examples of the difficulties encountered by colour defective individuals in this area have been reported, so a brief mention seems to be appropriate.

Frequently people with defective colour vision are aware of their difficulties in identifying colours of flowers or certain fruits growing. Holly berries and cherries are particularly common examples. One of the earliest records of the difficulties encountered by colour defectives involved a horticultural setting. HUDDART (1777) in his "account of persons who could not distinguish colours", describes the case of Harris, a shoe-maker, who could only distinguish cherries on a tree by their difference in size and shape. DALTON (1794) reports, just a few years later, of the accidental discovery of his own defective colour vision when he observed the colour of a geranium by candle-light -

> "the flower was pink, but it appeared to me almost an exact sky-blue by day; in candle-light, however, it was astonishingly changed, not having any blue in it, but being what I call red ..."

Market Gardening

The problem may be an old one, but it continues to cause difficulty. The problems experienced by colour defective nursery gardeners was raised with the present writer by a Dorset optician who was approached by a local market gardener whose major crop is tomatoes. He was experiencing problems because some of his staff were picking unripe green tomatoes, rather than the ripened red tomatoes. The optician was unable to help. Correspondence with the market gardener concerned revealed that they had been having problems for some time. Fruit was being picked either at a very immature stage, or was overlooked and hence not picked when ripe. At a subsequent picking two days later the tomatoes were so over-ripe that they had to be discarded as unfit for market. Not only was fruit wasted, but the process of grading was slowed down because fruit at the extreme range had to be separated. The market gardener was particularly concerned that with the tighter regulations imposed by the E.E.C. on grading, the inspectors would down-grade a sample of fruit because the colour range is too great. In addition they found that retailers are willing to pay a better price for fruit which is evenly matched for colour in each package. It was possible to advise the market gardener in question to screen new employees for defective colour vision and a magenta filter was provided to enable the colour defective tomato pickers to select the ripe fruit on the basis of the brightness difference. Information on the outcome of this matter is not yet available. A similar instance is reported in the 1946 Report on Defective Colour Vision in Industry.

Tobacco

The importance of good colour vision in the grading of tobacco was outlined in an article sponsored by the Rhodesian Tobacco Journal (1961). The financial risks can be very considerable indeed -

> "so savage is the price penalty the farmer pays for mixing greenish with true-coloured tobacco that completely muddled grading can almost ruin him."

the paper claimed.

Since the quality depends very largely on colour, fine visual colour judgements are made in many stages of the tobacco industry. Farmers who pick the tobacco leaves must obviously ensure that only the right crop is selected. In the auction rooms graders and buyers rely heavily on colour discrimination.

Colour vision testing using the Ishihara plates has been a standard feature for Rhodesian tobacco graders since 1961. A Salisbury ophthalmic optician hires out copies of the Ishihara plates to farmers who conduct the test under instructions (in particular the use of a daylight source is emphasized) and the results are interpreted by Mr. L. Bailey and Mr. B.D. Rivron, the ophthalmic opticians. The present writer was able to discuss the results with Mr. Bailey when he was in England. Over the period 1961-4, 1,241 African and 846 European persons were tested. A high incidence of failure was recorded in both groups - eighteen percent of African males and thirteen percent of European males were rejected. This seemed an unusually large number, but Mr. Bailey pointed out that failure to read one plate correctly was sufficient to disqualify the individual from grading work, since only those with perfect colour vision were considered acceptable. At the suggestion of Professor Fletcher of The City University a range of colour filters were used in an attempt to assist colour defectives in assessment of leaf colour. The four protan defectives were not helped by this method, but the deutan group of fourteen severe and twenty-two slight defectives were enabled to identify green spots and streakson tobacco leaves, indicating poor quality produce, using a magenta filter. Colour vision testing continues among the many thousands of Rhodesian tobacco farmers and graders.

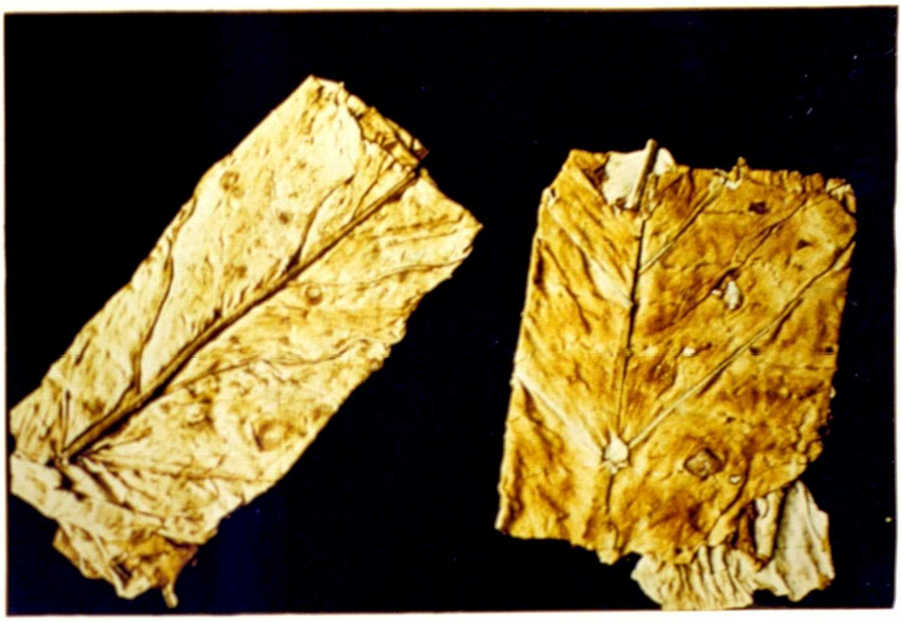
A visit was made to the British American Tobacco Company in London to discuss these problems further. The company completed a questionnaire indicating that colour vision played a major role in their leaf department and also involved a number of tobacco buyers. At least one buyer had experienced difficulty because of colour vision deficiency but no details were available. After this occurrence the Ishihara test was introduced as part of the medical examination for all candidates whose work would involve the grading and buying of tobacco leaves. One other tobacco, cigarette and snuff manufacturer returned a questionnaire and indicated that the Ishihara test was given in appropriate cases.

Tobacco leaves change colour throughout their life-cycles.

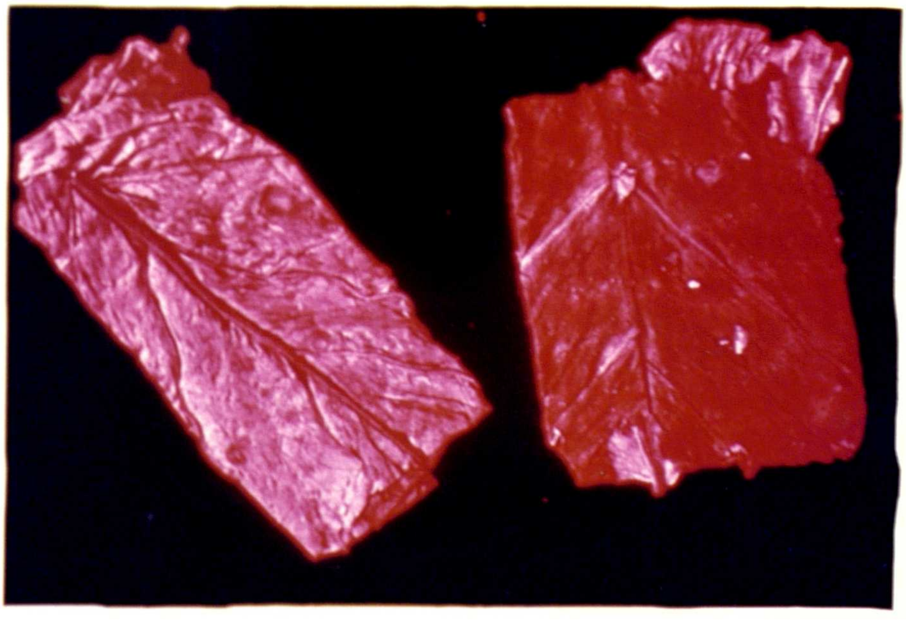
Raw, immature or crude tobacco is predominantly green, and any leaf which has a green colour affecting twenty percent or more of its surface is described as green. The leaf is usually purchased at this stage. In some countries leaves are offered to buyers on a colour basis with leaves of one shade grouped or graded together. During the ripening the leaf gradually changes in colour from green to yellow, orange, red and finally brown or sometimes grey. The latter colour indicates soil deficiencies. Thus the maturity is related to colour. Curing, the process of drying the sap either by natural or artificial processes, also affects the leaf colour; after curing the colour is maintained. The art of grading tobacco can take several years to accomplish.

Five or six thousand men are employed in the Rhodesian tobacco auction rooms and since 1963 a colour vision test (Ishihara) has been a standard part of the medical examination for people working in this capacity. It is more difficult to screen tobacco buyers for defective colour vision, and the responsibility for this must lie with the companies who employ them from many different parts of the world. More recently efforts have been made to standardize the illuminants used for the grading and sorting of tobacco leaves.

Tobacco Leaves



These two tobacco leaves look similar to a colour defective observer



Identification of the colour differences is possible for some colour defective observers using a magenta filter

Tobacco Leaves

Colour discrimination plays a major role in grading of tobacco.

LEATHER INDUSTRY

The leather industry has an active interest in colour vision and colour measurement[1] since tanners are frequently required to match colours very accurately. The British Leather Manufacturer Research Association indicated[1] that approximately 500 people are involved in this work throughout the industry. It is to be expected therefore that defective colour vision would impose a handicap for workers in this field. The British Leather Manufacturers Research Association[1] were unaware of any publications which were appropriate to the study, but were able to supply names and addresses of three leather firms in the London area to whom copies of the questionnaire were sent. Despite a reminder letter only one company returned the questionnaire. They indicated that eighty people are involved in visual colour judgement in varying degrees in the dyeing and colouring of leather. No colour vision test is given in this company and no mistakes that could be attributed to defective colour vision were reported. The B.L.R.A. also completed a questionnaire which indicated that seven people were involved in colour matching in dyeing and pigment finishing areas within the Association. The Ishihara test and the Colour Aptitude test is given by senior management to those concerned. A case of "poor reproducibility in analysis" resulting from defective

1. Written communication from Mr. Langstaff, British Leather Manufacturers Research Association.

colour vision was reported.

It is likely that this industry is one where widespread ignorance of the industrial consequences of colour vision defects may be displayed, but insufficient information makes a general assessment difficult.

MOTOR INDUSTRY

Careful colour control is required in the manufacture of car body parts and in particular the matching of spare parts of bodywork to existing vehicles. A wide range of colours is now offered by most car manufacturers. The method used to choose the colours and the procedures associated with the selection in the Ford Motor Company was outlined in a paper by CZELNY (1971). Marginal differences in colour can easily result in poor acceptance; hue differences in particular frequently render thematerial unacceptable. CZELNY points out that large stocks of coloured materials have to be held in plants in different geographical locations and that segregation of materials between plants on the basis of separate batch and dyelots is neither feasible nor practicable. Thus it is a common occurrence that a car seat-cover which is manufactured from three separate sections sewn together, will be made from materials representing three different dyeings. Very high standards in shade matching must therefore be maintained. CZELNY considers that despite instrumental techniques, the eye will remain the final arbiter in assessing the adequacy of shade matching in this industry.

It was considered to be worthwhile enquiring from the major manufacturers what role subjective assessment played in this industry and what colour vision test (if any) was given to eliminate colour defective observers from this work.

The Motor Industry Research Association did not know of any investigations which had been carried out on the role of colour vision in the industry and were only able to supply details of the colour coding system used foo the wiring of vehicles.

Only two major car manufacturers completed the questionnaire and they both indicated that only vehicle drivers and electricians were involved in colour judgement. The Ishihara test was given by the Medical Department to these employees in both companies. A third company, Vauxhall Motors of Luton, suggested that a visit would be most appropriate since both the Medical Adviser and one of the technical staff had a vague interest in the subject. Discussions revealed that in the Quality Control area colour identification decisions are eliminated asmuch as possible because of the need for consistency in mass production and colours are usually referred to by number rather than a name. Paints for body work are obtained from paint manufacturers who hold master samples, but an employee of the motor company has to check each batch of paint as it arrives to ensure that it is the correct colour. An artificial daylight source is used for this purpose. Mis-matching of the external paint of a car is seldom a problem because a complete "run" of cars of a particular colour is undertaken and colours are never mixed. One week spraying of cars yellow will take place, the next week green etc.

The Ishihara test is used in this company and every employee is given the test on entry. Failure to pass would not exclude an individual from employment; he would be put on non-colour work. Wiring seldom seems to present problems despite the coloured traces used in automobile wires as set out in B.S. Automobile series 7(1968) because wirings always relate to a specific function and electricians are familiar with the codes.

PAINT INDUSTRY

Subjective colour assessment is practiced throughout the paint industry and as in the ink industry, it seems unlikely that objective methods will take over in the near future. Considerable demands are made on the human eye in the colour matching field, although most of the critical work is confined to experienced laboratory staff and quality control personnel. As in the ink industry, technical staff are responsible for paint recipes and only a very minimal amount of colour matching is carried out by production staff.

Questionnaires were returned by ten paint companies all of whom were involved in fine colour matching work. Slightly more than fifty percent gave a routine colour vision test and this seemed a surprisingly low proportion for such an industry. However, one large company who employ twenty production staff and thirty R & D staff in key colour position, justify their failure to screen for defective colour vision by mentioning that colour decisions are never taken in isolation by one man. This may well be the case in other companies.

The use of "internal tests" presumably designed to the specifications of each company was quite widespread. This practice stems from the feeling expressed by one company that

"the Ishihara test is only regarded as suitable for assessing colour blindness and not ability to match colours. We use an additional internal test for this purpose."

The paint industry was one of the few industries where standard colour-matching tests, such as the I.S.C.C. colour aptitude test and the Davidson-Hemmendinger Colour Rule, were frequently used in addition to the Ishihara test. This practice was summed up by the Paint Research Association:

"The paint industry varies in its approach to colour vision testing. While it is clearly undesirable to use people with serious anomalies in their colour vision for colour matching, we are also concerned with selection of people with the highest sensitivity to colour differences for certain of the more exact requirements and for this purpose the colour aptitude test was developed in the USA and has been quite extensively used in this country."

The overall impression obtained is that some companies (particularly the larger ones) pay considerable attention to testing their employees for defective colour vision and colour aptitude while others do not bother at all. This is borne out in the remark made by one small company who had eight people involved in colour matching:

"we have neither the time nor the facilities to carry out the type of tests you mention. However, it may be of assistance to you to know that one of our best paint tinters is colour blind in that he cannot see red and yet he always manages to produce paint exactly to shade - we can only assume that over the years he has developed some automatic compensation for this."

Three companies quoted examples of mistakes that had been made due to the inability to distinguish colours on the part of employees.

"Difficulties have been encountered where personnel with slight Red/Green defects have difficulty in matching certain colours."

"Difficulties in metameric colour matching and colorimetric titrations."

"It is understood that a colour defective was employed on quality control work many years ago, but no evidence of serious error can be traced."

The 1946 Colour Group report on Defective Colour Vision in Industry noted that few cases of defective colour vision had been reported in the paint industry. The committee responsible for this report were informed by paint manufacturers that only a few employees require good colour vision, and in general this situation continues today.

PHARMACEUTICAL/COSMETICS INDUSTRY

Colour discrimination plays a significant role in this industry, especially in the cosmetics field, and particularly important in the chemical analysis of products and quality control areas. In the Pharmaceutical Industry the correct identification of colour might be a matter of life and death. Instrumental colour analysis is widespread in the chemical laboratories but good colour vision is necessary for many other processes - in particular the evaluation of end-point in chemical titrations. Visual colour matching is felt to be superior to instrumental methods for many purposes especially in the cosmetics industry. In the pharmaceutical area subjective colour judgements are made where the decision is not very critical and almost always to determine customer acceptability.

Fifteen companies completed the questionnaire, eleven pharmaceutical concerns and four leading cosmetic manufacturers.

Pharmaceuticals

Most pharmaceutical companies companies who returned the questionnaire showed an awareness of the possible difficulties which might result from employees with colour vision defects. Most gave a colour vision test (Ishihara) to prospective or new employees. Two of the four companies who did not test colour vision, did not have processes requiring colour identification. One company reported that:

"Ishihara deficient staff are often able to manage perfectly well in practice."

A visit was made to one leading pharmaceutical manufacturer where the author was received by a colour defective chemist! He had not been given a colour vision test when he joined the company some thirteen years previously, but a test has been introduced since. His main difficulty was with an indicator used to assess the hardness of water - magnesium and calcium with a reagent E.D.T.A. The colour change from purple to blue.

Colour control of pills and capsules

The colours are determined by dyes purchased elsewhere and new batches of dyes are checked thoroughly in the laboratory against a standard (visual match) and using instrumental means. Pill colours do not seem to vary widely within a given colour range; blue and green colours show greater variation than yellow and red pills. Consumer preference studies reveal a preference for red pills, which accounts for the popularity of this colour of pill. A trans lucent coating applied to a pill or capsule may alter the final colour of the product. It is difficult to define a colour acceptability range and few products are rejected on colour alone.

Colour coding of packages

Individual companies use different colours for different products and also operate a colour coding system for strengths of drugs. Correspondence with the Association of the British

Pharmaceutical Industry revealed that there is no central body which specifies the colour of markings for tablets and capsules and the colours are decided by each individual manufacturer. In general the Association is opposed to colour coding for the identification of medicines although it accepts the well-known colour code for insulin packs of different grades and strengths. The Bili-Labstix reagent strips for urine testing use a wide range of colours and require a match to be made against a standard chart supplied. The pharmaceutical company visited always specified the name of the drug in words as well as using a colour coded system for identification.

Cosmetics

The four leading cosmetic manufactu rers who completed the questionnaire all stated that critical colour judgements were required in R & D departments and chemical laboratories. Quality control personnel were heavily involved in colour work and many production workers were also required to recognise small colour differences.

The numbers involved in a single company averaged fifty. All four companies gave the Ishihara test to personnel working on coloured products. Two companies mentioned that isolated mistakes had been made due to defective colour vision. In one case a powder compounder working on critical colour matching was found to have defective colour vision; he was transferred to another department. In another company an acquired defect of colour vision accompanying an ocular pathological condition was noticed in a person who had previously passed the Ishihara test at a pre-employment medical examination. He incorrectly approved coloured products. Communication broke down between a cosmetic company and their packaging supplier when they could not agree on the naming of a colour on the telephone. The packaging representative was later found to have defective colour vision.

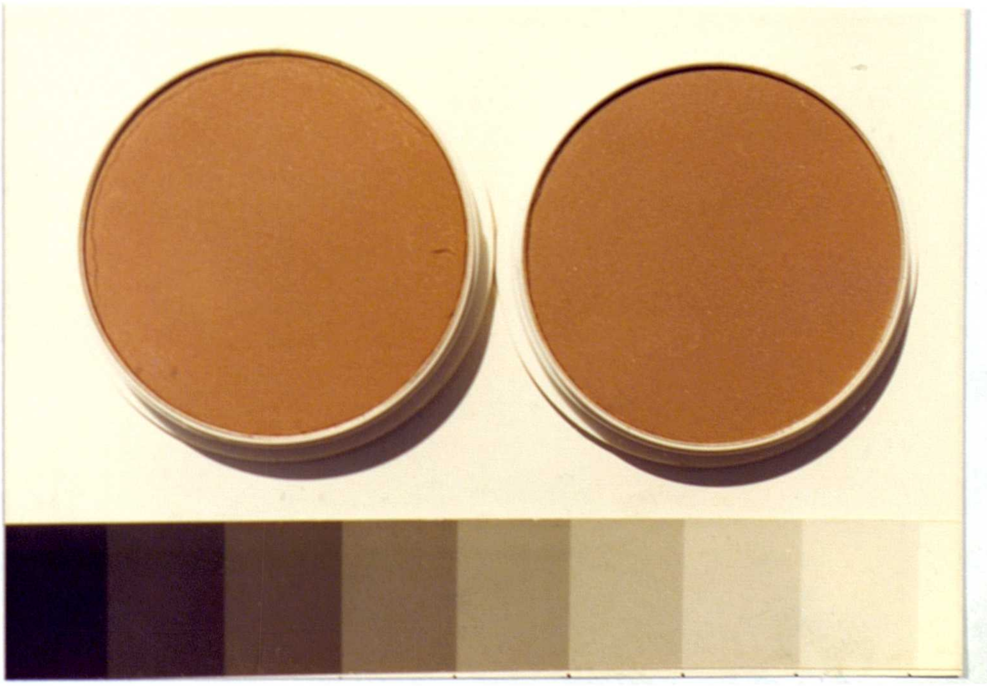
A visit was made to one leading cosmetics manufacturer, and it was evident that colour is extremely critical in this industry.

> "If the colour of the product is correct then it goes, even if another aspect is incorrect."

was the comment. The company relies almost exclusively on visual colourmatching and all colours are finally assessed on human skin. Lipstick colours "mature" or become slightly bluer with age owing to moisture from the atmosphere so that an allowance must be made for this and the match is made erring on the yellow side. This is done entirely from experience. Women are mainly concerned with production work and many laboratory and quality control jobs.

Cosmetics Samples

Colour control is a most important feature of the cosmetics industry. Production samples are matched against standard control samples.



These samples show unacceptable differences in colour

Pharmaceutical Samples

PAPER AND PRINTING INDUSTRY

Despite a recent move towards the introduction of instrumental methods for the colour analysis of plain paper, and electronic scanning techniques to assess the quality of colour printing, visual colour judgement is still relied upon throughout the paper and printing industry. Subjective assessment is considered to be superior to technological methods by most companies and it is difficult to envisage a situation where instrumental methods will take over the visual aspect entirely. As A.E. Bardouleau pointed out in a lecture to the Third Symposium on colour organised by The Colour Group (G.B.) in April 1971, printing is still a craft-based industry and the average colour printer sees himself as a minor artist whose job it is to make the best result to his eye.

The need for good colour discrimination in operatives involved in colour decisions is realised in both sections of the industry. Tests for defective colour vision are carried out in most large companies today. However, almost half of the paper and printing production in the U.K. takes place in small firms where a colour vision test is seldom given[1].

The 1946 report on defective colour vision in Industry mentioned the extensive pre-vocational testing of Scottish

1. Personal telephone conversation with A. Johnston, Printing and Packaging Research Association, Leatherhead.

printing apprentices and the very limited colour vision testing in individual companies. While it is still true that screening for defective colour vision is frequently a part of an apprentice selection scheme enquiries have revealed that there is no overall National policy within the printing industry and individual companies would be well advised to carry out their own tests.

Union Involvement

The paper and printing industry is heavily involved with the major trade unions. Of these, the Society of Lithographic Artists, Designers, Engravers and Process Workers (S.L.A.D.E.) is mainly concerned with employees engaged in the pre-printing stage. The National Graphical Association (N.G.A.) deals with printers, and the National Society of Operative Printers, Graphical and Media Personnel (N.A.T.S.O.P.A.) is mainly concerned with printers and book-binders. The majority of people requiring employment in the industry apply to individual companies for employment, but the trade unions can specify the numbers of apprentices that will be engaged each year.

The Printing and Publishing Industry Training Board is concerned with a number of apprentice selection schemes and constantly renew the terms of employment. It indicates[1] that since

1. Personal communication, written, 30th January 1974

normal colour vision is essential for some aspects of printing, a colour vision test - generally the Ishihara test - forms part of the selection procedure. They make recommendations to various firms and organisations stressing the importance of good colourvision for apprentices.[1] However, correspondence with the S.L.A.D.E. Union[2] indicates that there is no national policy for the testing of apprentices for defective colour vision. The British Master Printer's Association confirm this statement[3] and indicate that regional groups provide their own selection procedures. One regional group, the London Master Printer's Association[4] include the Ishihara test in a general medical examination. Individuals who are likely to be very much involved in critical colour work are sent to the London College of Printing for a practical test which involves the copying of a simple coloured picture[5]. In the Edinburgh region a link has been established between the University Psychology Department and the printing industry over many years (perhaps even back to the 1930's). Dr. R. Lakowski, and more recently, Dr. P. Aspinall,

1. Personal written communication with National Officer of the National Graphical Association, 23 November 1973

2. Personal written communication with Secretary and Secretary General 30th November 1973.

3. Personal telephone communication with Mr. Putman, 22nd January 1974

4. Personal telephone communication 22nd January 1974 with secretary

5. This was discussed with Mr. G. Gough, The London College of Printing January 1974.

have tested about sixty boys each year with a battery of colour vision tests.[1]

The S.L.A.D.E. Union were aware[2] of the need for good colour discrimination in the majority of workers in the printing industry, but did not know what tests, if any, were given. A more positive awareness of the need for colour vision testing was shown by the National Graphical Association. They indicate[3] great interest in this aspect of a printer's ability , which they have been aware of for some considerable time, and say

"we are doing all we can to get it properly recognised."

for many years the N.G.A. have been trying to persuade the various organisations involved that a colour vision test should be a greater part of the initial examination/selection procedure. A letter to N.A.T.S.O.P.A. prompted the National Assistant Secretary to bring the question of colour vision testing to the attention of the Printing Safety Group. The Group subsequently discussed the issue and felt that the matter was more appropriate to those concerned with the selection of people entering the printing industry.[4]

1. Personal written communication with Dr. P. Aspinall 5th February 1974

2. Personal written communication with General Secretary 16th November 1973

3. Personal writtencommunication with The National Officer 23rd November 1973

4. Personal written communication with the National Assistant Secretary 28th January 1974.

These comments indicate a certain degree of confusion as to whose responsibility it is to test the colour vision of entrants to the printing industry, and the readermay wonder how long this state of affairs will persist.

Such findings, which have also come out of this study in other sections, make it possible for the present writer to offer positive recommendations, which if taken up should greatly improve industrial efficiency and could circumvent considerable human unhappiness. It is reasonable to suggest that the ultimate responsibility to detect and eliminate colour defective individuals who are at risk in their daily work, must lie with the individual companies, testing should preferably be done before engaging new personnel on colour work. On the other hand, pre-vocational testing of colour vision should be encouraged by the Trade Unions and apprentice selection boards. They also have the responsibility to eliminate the distress and wastage which the disco very of a colour vision defect must certainly cause to individuals who have settled on a chosen career.

<u>Paper Manufacturers</u>

All companies contacted, except one, considered that subjective assessment of paper colour was superior in many respects to the currently available instruments for this purpose, and the important role of the human observer was acknowledged.

The unaided eye can detect visual differences which are smaller than those detected by instrumental means - especially in the near-white and desaturated tints where the eye can detect less than 0.0003 difference in chromaticity. This is an important factor in the batching-up of paper sheets where the tolerance is of the order of ± 0.001. It is not surprising therefore, that this industry revealed an extreme example of the difficulty that would be encountered by the colour defective observer.

One of the major colour tasks in the manufacture of paper involves the matching of coloured, white and near-white paper to the master standard under a standard illuminant. For several years controlled illumination conditions have been a standard feature of the printing and paper industry; these are set out in B.S. 950 Parts I and II.[1] The colour matcher is required to detect small colour differences or colour additions and usually advises on the changes required if the production sample does not fall within the accepted tolerance. To facilitate this operation, single dyes are used, where possible, for coloured paper by many manufacturers.

Laboratory staff - mostly analytical chemists - and quality control inspectors are also required to exercise fine colour

1. Part I deals with the illuminant for colour matching and appraisal and recommends a source of correlated colour temperature 6500K for this purpose.
Part II concerns viewing conditions for the graphic arts and recommends a slightly redder source of correlated colour temperature 5000K.

judgement. Consumer representatives who inspect the final product before or after delivery are also required to exercise very fine colour judgement.

Questionnaires were returned by eleven paper manufacturers. Of these four did not give a colour vision test to new staff. Out of the seven companies who gave the Ishihara test (usually under a suitable illuminant) to prospective employees concerned with colour work, four mentioned that mistakes had been made in the past by colour defective staff. It is likely that these instances promoted the introduction of routine screening. It seems probable that the four companies who did not test for abnormal colour vision in their staff are likely to encounter mistakes before very long. The Committee responsible for the 1946 Report on Defective Colour Vision in Industry were unable to trace any tests being applied in the paper industry.

The Printing and Packaging Research Association (P.I.R.A.) have tested large numbers of printing/paper workers in recent years,[1] but no longer continue this on a large scale . During the years 1972-4 they advised a change or restriction of employment in about fifteen cases from a total of six hundred people tested. The I.S.C.C. Colour Aptitude test and the Pickford-Nicholson anomaloscope have been used with the Ishihara test for this purpose.

1. Private written communication with Mr. A.E. Bardouleau (P.I.R.A.)

Visits were made to two large paper mills in the South-East of England to gain a first-hand impression of the jobs that require good colour discrimination. In both companies one or two colour defective people were employed because they had been engaged before testing was introduced. In one case a red defective worker, who had been taken on by the company many years ago, was actually involved in the colour assessment of paper. His expertise led to promotion as a foreman, but it was pointed out that

> "he manages quite well because everyone knows of his defect and he seeks advice if he is in difficulty"

The same company introduc ed the Ishihara test some five years ago when the factory increased its range to coloured papers. Questioning revealed, however, that they were far from satisfied with the test, feeling it to be

> "inadequate and completely unsophisticated".

In the other large mill visited, the biggest within a National Group, thirty people were employed on colour assessment work. Within the whole group over a hundred and fifty production staff and a similar number of laboratory staff are involved in visual colour judgement. The chief colourist is very aware of the necessity for and the desir ability of good colour discrimination.in colour workers. The Ishihara test has been given (under a suitable illuminant) at the initial interview for about twenty years. Five cases of defective colour vision have been found out of a total of seventy-eight applicants. Failures on the Ishihara test are rejected from employment with the company. This is unusually severe - many companies offer alternative employment not involving colour discrimination. Short-listed candidates for posts as colour-matchers are given the I.S.C.C. Colour Aptitude test and successful applicants are taken on for a three month trial period. Complete training takes one year. A number of elderly colour-matchers are employed by the company and no allowance is made for changes in colour discrimination with age. It is possible that experience may off-set this factor partially.

Over thirty percent of the factory output, involving the production of laminate based coloured papers, is considered to be of a very critical nature colour-wise. Care is taken to restrict the number of pigments used where possible. The opportunity was given to discuss with a strong green colour defective operative, (probably a deuteranope), the problems that he experienced with the matching of formica laminates. Wood-grain patterns gave him the grea test problems and he was no longer involved in colour work because he did not feel confident to make the necessary decisions. Nevertheless he felt that over many years in the paper industry he had learned to compensate for his defect to some extent.

In another paper mill of the same com pany only ten men were concerned with daily colour decisions. One man who was later found to be colour defective, was discovered after four years employment in the factory because he had made an important mistake.

The number of people in key colour positions was found to vary considerably between companies. One large wall-paper manufacturer reported that many hundreds of personnel were involved in colour work. A major paper company required two hundred people to make colour judgements in the production, laboratory and inspection fields. Both companies reported using the Ishihara test. In a smaller paper company only twenty-five production and inspection workers and two laboratory assistants were concerned. It was pleasing to note that despite small numbers the Ishihara test was given at this company. The possibility of mistakes occurring among the twelve individuals entrusted with colour work at another small paper company had obviously not been realised because no test was given.

Several interesting comments were made by those who completed the questionnaires. References are not given to keep faith with the anonimity which was promised. One company reported that they were involved in

> "considerable amounts of visual matching of white and coloured papers."

They doubted very much whether any screening for colour vision was undertaken, or at least whether any action was taken if a colour vision test was included in the medical check-up for paper-makers. Another company felt that it was "highly likely" that mistakes had been made as a result of a colour vision defect, but thought that they must have been of a minor nature or they would have been discovered.

The I.S.C.C. Colour Aptitude test is used by some paint, ink and paper manufacturers. A paper manufacturer who used the test in addition to the Ishihara test seemed to be disappointed with it, mentioning that

> "there is no conclusive proof that people who perform well at the test are also good at their jobs."

Several mistakes had been recorded which could be directly attributed to colour vision defects. This indicates that a considerable number of colour defective people are employed in colour work in the industry. The Research and Development Centre of one large paper manufacturer admitted that one of their chief chemists, an expert in chemical colour formulation was red-green defective, but he did not seem to have suffered from his deficiency. Another company knew of an acquired defect in a colour matcher. Too much dye had been added to a paper by a colour defective in another mill, resulting in an incorrect colour match, although it appeared correct to the man involved.

Only one group of paper manufacturers reported using instrumental methods for most of their colour matching. As a result under fifty people were involved in visual assessment.

Printing Industry

Over the last twenty years the volume of coloured printing matter compared with monochrome material has increased enormously and a high standard of colour reproduction is now maintained in magazines, packages etc. Since there is a big demand for high quality colour illustrated publications and competition is stiff, colour printing has become the accepted norm and choice of the colours used for printed packages strongly influences the consumer. SACHAROW (1970) This author found that orange and red and blue attracted the best attention, but yellow was generally regarded as a cheap colour.

The need for accurate colour reproduction is felt particularly in the many postal sales, colour catalogues where goods are displayed and customers select items for purchase, often on the basis of the colours shown e.g. colours of garments. The Representation of Goods Act requires a faithful reproduction of sales products when portrayed in catalogue form. Colour printing is a very competitive business and every effort is made to maintain high standards. It is therefore to be expected that many jobs in this industry demand careful visual colour appraisal on the part of many printing operatives. Because printing pigments are imperfect, colour corrections must be made by skilled operatives who work as colour retouchers. One large printing company visited by the author required almost half of its 2,500 employees to make visual colour judgements during their daily work.

As in the paper industry there is careful adherence to the standard illuminant set out in B.S.950 Part II in the printing industry for colour appraisal work. It was pleasing to discover a considerable awareness among the representatives of the industry who were contacted, of the need for good colour discrimination and the penal ties of colour defective individuals on colour work.

Questionnaires were returned by five large printing companies concerned with colour work and two smaller companies. One of the latter employed only eighty people, of whom just twelve were directly involved in colour assessment. All those companies who returned the questionnaire, except the smaller firm mentioned, indicated that a colour vision test was given at the pre-employment stage. In every case the Ishihara test was used except in one case where the H.R.R. plates were used. One company also gave the Farnsworth-Munsell 100 Hue Test, in addition to the Ishihara plates to technical staff.

Because of the importance of colour in the printing industry and the large numbers of people involved in colour work within this industry, it was felt to be worthwhile to visit three large colour printing companies, one large publishing company and one smaller colour printing works.

Company No.1

Half of the 2,500 employees are engaged in daily visual colour assessment.

Jobs requiring good colour vision

1. Examination of original material, colour separations and hand corrections for the four colour printing processes.
2. Colour retouching by skilled craftsmen.
3. Ink department, where coloured inks are compared with standard samples.
4. Evaluation and scanning by electronic methods also requires a final visual assessment.
5. Visual colour judgement between original transparency and duplicates. Assessment of the printed copy.

Colour Vision Testing Policy

Recently new apprentices and laboratory workers have been screened on the Ishihara test, but no other employees are given the test. The test is not carried out under daylight illumination - tungsten is used.

The company were aware that several colour retouchers had difficulty with colours and might be colour defectives, but they managed to compensate and produce acceptable work.

Company No.2

Employees over one hundred colour retouchers who spend from one third of a day to three days correcting a picture. This is a particularly critical area demanding excellent colour discrimination. A further two hundred people are required to make subjective colour assessment. Although electronic colour matching is now routine for 75% of the work, a visual ju gement must be made when this procedure is completed.

<u>Testing Policy</u>

Apprentices are tested *on the Ishihara test on arrival. The* technical manager responsible feels that

> "the Ishihara test is not adequate for our situation and in general too little attention is paid to the whole problem, especially changes due to ageing."

He pointed out the difficulties involved because

> "this is a highly sensitive area in terms of human relations."

<u>Company No.3</u>

This company is primarily concerned with the manufacture of G.P.O. postage stamps, trading stamps and mail order catalogues. Between fifty and one hundred people are involved in colour work.

> "We are very concerned with assessment and control of colour, particularly for postage stamps. We depend very largely on subjective judgements since these appear at the moment to be superior in most respects to the instrumental methods available."

<u>Testing Policy</u>

For ten years the Ishihara test has been given to all applicants. Those who fail are rejected from employment. Twenty women inspect 20,000 stamps a day each, for faults, including colour variations. This job is a most critical and demanding task colour-wise.

Choice of colours for G.P.O. postage stamps

Investigations into how the choice of colours used by the G.P.O. for postage stamps was made was felt to be worthwhile.[1] In particular the author wished to establish whether the problems that a colour defective postal worker (or even a postal user) might have in identifying the colours of stamps had been considered. The G.P.O. have a stamp advisory/selection Board which meets regularly to discuss the choice of colours. for further editions of postage stamps. The colours of ordinary editions are chosen with aesthetic and ease of identification considerations in mind. Special editions are designed by artists who are responsible for the choice of colour. Dr. I. Brown of the M.R.C. Applied Psychology Unit at Cambridge has been responsible for advising the G.P.O. on the most suitable colours for postage stamps. Care has been taken to avoid very similar colours which would cause difficulties for colour normals. Browns are thought to give the most difficulty. Around 1968/9 colour changes were made because the lighting in post offices made it difficult to distinguish between brown and blue stamps. The new colours, bright blue and orange were used instead.

1. Personal telephone communication with:

   (a) Mr. York, Harrisons & Co. Ltd., High Wycombe
   Representative of Harrisons on G.P.O. Stamp
   Selection Board.

   (b) Miss Ladbury G.P.O. 26th June 1976
   Mr. T. Rose G.P.O. Postal Headquarters.

The problems of the colour defective have been considered in a nominal way only. The Board are aware of the possible problems, but no work has been done or thought given to reduce the hazard. It is likely that increased mechanisation of postal sorting will reduce the need for visual identification in the near future.

Company No.4 - Publishing Group

A visit was made to the research department of the largest publishing group within the U.K. The research and technical department has recently looked into the question of colour vision testing and has introduced the use of the Farnsworth-Munsell 100 Hue Test for laboratory staff and

"anyone we can persuade to do the test."

Printers, colour retouchers, photograpers, quality control staff and advertising representatives have been tested.

The special difficulties which arise when dealing with the latter group were emphasised. Representatives of advertising agencies have to make critical colour judgements when evaluating colour reproductions to decide whether or not they are satisfied with the colours.

Complaints are then discussed. Occasionally the printer/publisher has experienced difficulty in reaching an understanding with agents because of the differences in viewing conditions or the colour vision of observers who are comparing and assessing colours. This is especially noticeable when negotiations are conducted over the telephone or in writing.

Recently a degree of co-operation has been achieved and standard illuminants are now used by many advertising agencies. Widespread colour vision testing of these personnel is yet to be achieved. A questionnaire was sent to ten major advertising agencies to ask if the colour vision of those persons involved in colour appraisal work was known to be normal. Unfortunately no replies were received.

The difficulties of enforcing the use of a standard colour vision test throughout all factory locations within the group were explained. The Research group encouraged testing, and were always pleased to give advice to individual factories, but the decision of whether or not to test colour vision remains at the discretion of each location manger and it was thought that a test was seldom given in practice. The offer made by the Research Group to test the colour vision of production staff was seldom taken up.

Company No. 5 - Small Printing/Engraving Company

Only twenty-three men are involved in colour-retouching/engraving/etching in this small company. The management are aware of the need for good colour vision in colour workers because two men who completed their apprenticeship were recently found to have defective colour vision and both have had to retrain. Understandably they feel that testing should be carried out before the apprenticeship commences. They use the H.R.R. plates for all prospective employees.

Two sections of the colour printing industry demand the highest standards of colour judgement - in the manufacture of wallpapers, where small colour differences are quickly spotted by the eye, and in the production of colour shade guides for the paint, cosmetic and allied industries.
A questionnaire was sent to a major representative of each of these areas. It was pleasing to note that both were aware of the possible difficulties that would arise if colour defective individuals were placed in colour-responsible positions, and both sought to eliminate this hazard by employing only colour normals for critical colour work.

PRINTING INK INDUSTRY

Colour matching in the printing ink industry is very critical and the highest standards of colour vision are necessary by those involved in this aspect of the work. Subjective matching is used almost exclusively and the manufacturers consulted did not foresee a move towards instrumental methods. The eye is considered to be far superior to instruments for this purpose. Critical colour decisions are confined to laboratory staff who are responsible for producing a recipe for ink which matches a customer's request.

Fifteen companies returned the questionnaire. All companies represented gave a standard colour vision test (Ishihara in all cases) to new entrants and failure at the test would restrict activities.considerably. The number concerned with critical colour evaluation within a single company varied from five to over a hundred. No mistakes which could be attributed to defective colour vision were reported.

Visits were made to two leading liquid ink manufacturers. Ink colour matchers train for a period of approximately eighteen months and even experienced matchers seldom take a decision alone. Laboratory staff mix powdered dyes to match a specimen colour supplied by the customer and a comparison with the standard colour is carried out until an acceptable match has been achieved. This procedure involves a combination of experience, judgement and trial and error. Difficult colours may involve several mixtures before an acceptable match is achieved. Using different substrates frequently complicates the procedure and there is an infinite range of colour mixtures. Complaints on the basis of mis-matching are, nevertheless, rare. Production staff are minimally involved in colour decisions since they work specifically to the recipe produced by the laboratory staff.

Contact was made with one mildly deuteranomalous trichromat in one large printing ink company. He was involved in critical colour matching work, but managed well except in greens when he consulted a colleague. It was not known how he had been overlooked and had been accepted to work in this type of work, despite a pre-employment medical examination when an Ishihara test had been given. In this industry which is obviously very colour-orientated, a degree of self-selection occurs and experience has shown that few colour defective people apply to work in this field. Investigations made by the Colour Group Committee who were considering the subject of defective colour vision in Industry in 1946 resulted in a conclusion that few cases of defective colour vision were reported among workers in the printing ink industry. Certain colours were found to be more difficult to match, particularly the paler shades of grey and brown and dark blue. Reds and greens were generally considered to be easy colours to match, but it is likely that this difference is based on the dye chemistry, availability of pigments etc. rather than visual considerations.

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Personal Particulars

Surname..

Address..

....

....

Date of birth......................................

Place of birth.....................................

Nationality at birth...............................

Nationality now....................................

Married or Single..................................

Number of Children.................................

Ages of Children...................................

Christian Names....................................

Telephone: Home....................................

Business...

State of health (Give details of any serious illnesses or disabilities)

....

....

Are you — Colour Blind? ....
(Defective colour vision is an absolute disqualification for technical appointments)

Allergic to Solvents?..............................

Have you had a skin infection?.....................

Painting artifical eyes

Table 64

Summary of colour vision requirements and colour vision testing in industry based on data obtained from questionnaires and personal visits.

Industry	Jobs requiring good Colour Discrimination	Number of Questionnaires returned	Colour Vision Test given Yes/No
Bricks	Many production jobs e.g. persons who mix pigments persons who load/unload kilns inspection/sorting of finished goods	3	No
Ceramics			
1. Porcelain	Selection/mixing of glazes Hand painting/decorating of tableware and figures Inspection of finished goods	8	Most No
2. Tiles/ Sanitary-ware	Selection/mixing of glazes Colour matching against a standard. Quality Control Inspection	4	No
Cosmetics	Many production jobs Chemical analysis Colour matching of product against a standard Buyers	4	Yes
Electrical	Inspection of cable finishes Assembly of cables e.g. rack wire-men cable joiners Switch panel assemblers Telephone Exchange assemblers/ installers Assessment of colour T.V. equipment Production of colour coded resistors and capacitors.	16	Approximately 50% Yes

Industry	Jobs requiring good colour discrimination	Number of questionnaires returned	Colour vision Test given Yes/No
Food	Many production jobs Sorting/selection of ingredients e.g. soups, biscuits, frozen vegetables Preparation of foodstuffs e.g. meat, pastes, chocolate Grading of foodstuffs e.g. flour, salt, sugar Appraisal of food stuffs, e.g. beer Buyers	35	Approximately 50% Yes
Furniture	Checking deliveries of materials e.g. wood and fabrics Laying/cutting/matching of fabrics Sewing/matching fabrics Matching wood grains Buyers (to some extent)	4	No
Glass	Mixing/selection of pigments Inspection of finished product for colour faults	3	Most Yes
Heavy Metals	Chemical analysis Metallurgy Inspection of metal for defects Microscopic analytical inspection for defects Grading and analysis of compounds.	8	Most Yes
Inks	Inspection of new materials Laboratory/Technical staff concerned with colour matching against a standard and formulation of recipe Quality Control Buyers.	15	Most Yes
Jewellery	Visual Colour grading of gems Particularly important and critical for diamonds.	1	No

Industry	Jobs requiring good colour discrimination	Number of question-naires returned	Colour Vision Test given Yes/No
Leather	Tanners - matching of colours of leather	1	No
Motor	Electrical wiring of cars Colour matching of bodywork Colour matching of interior upholstery Vehicle drivers	2	Yes
Paper	Matching of white and coloured paper to standard	11	Most Yes
Printing	Colour Printing- numerous jobs e.g. Retouching Evaluation Etching Ink Dept. Photographers Inspection	7	Yes
Paints	Inspection of new Materials Technical/Laboratory Depts. concerned with colour matching against a standard and formulation of recipe chemical analysis Quality control Buyers	10	Approximately 50% Yes
Pharma-ceutical	Inspection of raw materials Chemical analysis Quality control	15	Most Yes
Textiles	Many production jobs		
1. Carpets	Colour matching Sorting of raw materials Dyeing Winding bobbins Setting looms Weaving Inspection of finished goods Salesmen Buyers	5	Yes
2. Dyeing and general textile production	Many production jobs Dyers Colour matching of Fabrics yarns, hoisery and knitwear	23	Most Yes

Industry	Jobs requiring good colour discrimination	Number of questionnaires returned	Colour Vision Test given Yes/No
Tobacco	Buyers Grading and assessment of leaf tobacco.	2	Yes

3.2 Comments made by Employment Medical Advisers

The Employment Medical Advisory Service (E.M.A.S.) is concerned with advising individuals and their employers on industrial health hazards and problems, and the suitability of employing individuals who suffer from, or are prone to, particular medical conditions in certain occupations. The service is responsible for only a small highly selected group of young people, those for whom a form Y9 has been completed by the School Health Service and who subsequently enter employment covered by the Factories Act of 1961. Colour vision defects are recorded on form Y9 and consideration is therefore given in each case to the suitability of employment. The Service operates on a regional basis with nine regions within Great Britain, each supervised by a Regional Employment Medical Adviser. A total of seventy full-time and forty part-time employment Medical advisers operate throughout the nine regions.

A personal letter was sent to each Regional Adviser informing him of the study and asking for information from his experience which might be pertinent; eight advisers replied; their comments are given below:

Dr. G. Ritchie. South West Region, Bristol

Dr. Ritchie thought that colour vision tests are given in most industries where colour plays an important role. The tests used in his experience,are the Ishihara test or the identification of coloured threads or wires. He considered that in most industries this appears to be sufficient to pick out those who have defective colour vision.

Dr. D. Trott. Eastern and S.E. Midlands Region, Watford

Dr. Trott considered that very few young people are advised or have to change their occupation through having colour vision defects, although he did not have quantitative evidence to support this view. He noted that even in those cases where colour vision is considered to be very important, i.e. electrical circuitry, pigment and paint blending etc., it is often found that the sufferer in spite of his "chart defect" passes an "on site" test at an adequate level. He was unable to recall any mistakes which gave rise to untoward effects in industry, among persons with colour vision defects.

Dr. J. Bell. Northern Region, Newcastle-on-Tyne

Dr Bell thought that many individuals were probably rejected for a given employment on account of a failed Ishihara test, when in fact, the defect is either slight, or the nature of the work is such that even total red/green deficiency would be unlikely to affect the ability to perform the job in question. He knew of no mistakes that had been made in the north of England resulting in accidents or injuries, in the past three years where defective colour vision had been a factor. He hoped that during the study an assessment would be made of the real importance of colour vision deficiency in work where traditionally normal colour vision has been thought necessary.

Dr. G. Fletcher. North Western Region. Manchester

Dr. Fletcher reported few findings in the way of industrial consequences of colour vision defects. He used the Ishihara test and a matching task using coloured wires, but felt the Ishihara to be too severe for practical screening since it resulted in a classification which had little practical significance. He expressed an impression of a very considerable degree of self-selection occurring so that few problems were encountered in the placing of colour defectives in suitable jobs. The case of a young man showing red-green defects on the Ishihara test, who was employed in a garage mixing paints for repair work because of his ability to match shades of paint, was quoted to support his views.

Dr. E. Blackadder. Scottish Region. Glasgow

Dr. Blackadder was aware of the limitations of the present methods of assessing colour vision defects, in particular the limitations in predicting accuracy of performance in the work situation. The Ishihara test and a trade test involving identification and matching of multi-coloured wires are used, and frequent cases occur where individuals fail the Ishihara test quite badly, but are competent at performing the trade test. Dr. Blackadder felt that many young people have had their career hopes frustrated, perhaps unnecessarily, due to minor degrees of colour vision defect being detected by pre-employment medical examinations.

Dr. A. Jones. Welsh Region, Cardiff

Dr. Jones based his comments on his previous experience as Medical officer to the Railways. He said that he had developed some rather definite views after carrying out many thousands of colour vision examinations for a large range of occupations. He prefered to distinguish clearly between a physiological test of colour discrimination (quoting the Ishihara test, the anomaloscope and the F-M 100 Hue test as examples) and a task orientated or trade test such as the Holmgren wool test, coloured wire tests and lanterns. He considered that the latter type of test has the serious disadvantage that it measures a man's ability to name or match colours at the time the test is administered, but at no other time. He felt that it is "quite wrong" to accept a normal performance on this type of test as evidence of normal colour vision when physiological tests give indications to the contrary. Furthermore he considered the task orientated test to be quite inappropriate where colour vision is thought to be essential for safety, although he admitted that they might have a place as an aptitude assessment for colour matching tests in the clothing trade or textile industry. Dr. Jones emphasised the need to ask what significance a colour vision defect discovered by a physiological test (e.g. Ishihara) has in task performance. He noted that there is only one piece of anecdotal evidence, as far as he was aware, that a colour vision defect had ever led to an accident in this country; that was in the case of a signal wiring mistake on London Transport in the 1930's.

It is clear from these written comments and also from personal discussions with a number of Industrial Medical Advisers that few are entirely satisfied with the colour vision tests used in industrial situations today e.g. the Ishihara test and a trade test which usually involves the identification of coloured wires. The dissatisfaction arises because the Ishihara test is felt to be of little practical significance, since many individuals who fail it have proved to be capable of industrial colour jobs. This may lead to unnecessary and unfair discrimination against those who fail. Trade tests are often favoured for prospective electrical employees, but, as one industrial medical officer pointed out, performance is not always consistent.

No mistakes that had occurred in industry which could be attributed to defective colour vision were reported. Some respondents felt that a degree of self-selection occurred in colour industries and were aware of few young people who had had tochange their occupation because of a colour vision defect.

SECTION IV

SIMULATED INDUSTRIAL TASKS

Performance of colour normal and colour defective observers

A series of simulated industrial colour tasks were designed to investigate how well colour defective observers, and a small number of colour normal control observers performed at such tasks, in an effort to evaluate just how handicapped the colour defective observer would be at a particular colour job. Five major takks involving the electrieal, printing/ photographic, textile and food industries were designed.

SLOAN AND ALTMANN (1951) stress the need for standard colour vision tests to be compared with performances at colour tasks required by the various occupations. Few studies on this aspect of colour vision deficiences have been published to date.

LAKOWSKI (1968) feels that it is more important to discover whether a man is able to do a particular job than to classify him as colour normal or colour defective in some way. He considers that the results of colour vision tests alone are not enough if an effort is to be made to avoid rejecting the suitable and accepting the unsuitable for a particular occupation.

An attempt has been made in this study to evaluate the use of "trade" tests and compare these with standard colour vision tests for industrial use.

IV.1 OIL TRIAL

Samples of six different mineral oils, all either yellow or brown-yellow in colour, and of approximately the same viscosity, supplied by the Burmah Castrol Company, were provided by the medical department of H.J. Heinz Limited, as an example of a trade test involving colour. The test was previously used by the company for engineers in the workshop, but has since been withdrawn. The employees were required to identify the coloured oils by name; colour recognition played an important part in this procedure. The colours of the oils were measured with a Lovibond Schofield Tintometer visual colorimeter[1] to obtain the chromaticity co-ordinates and luminance values. The results are presented in Table 3 . When these were plotted on the C.I.E. x,y chromaticity diagram (see figure 5), it was evident that some of the colours lay along, or very close to, the confusion loci of dichromats and might therefore be confused by colour defective observers.

The samples were divided into twelve bottles forming six pairs, and were coded to facilitate identification by the examiner. Thirty-five colour defective observers

1. By courtesy of D. Chamberlain, Esq. of Tintometer ltd.

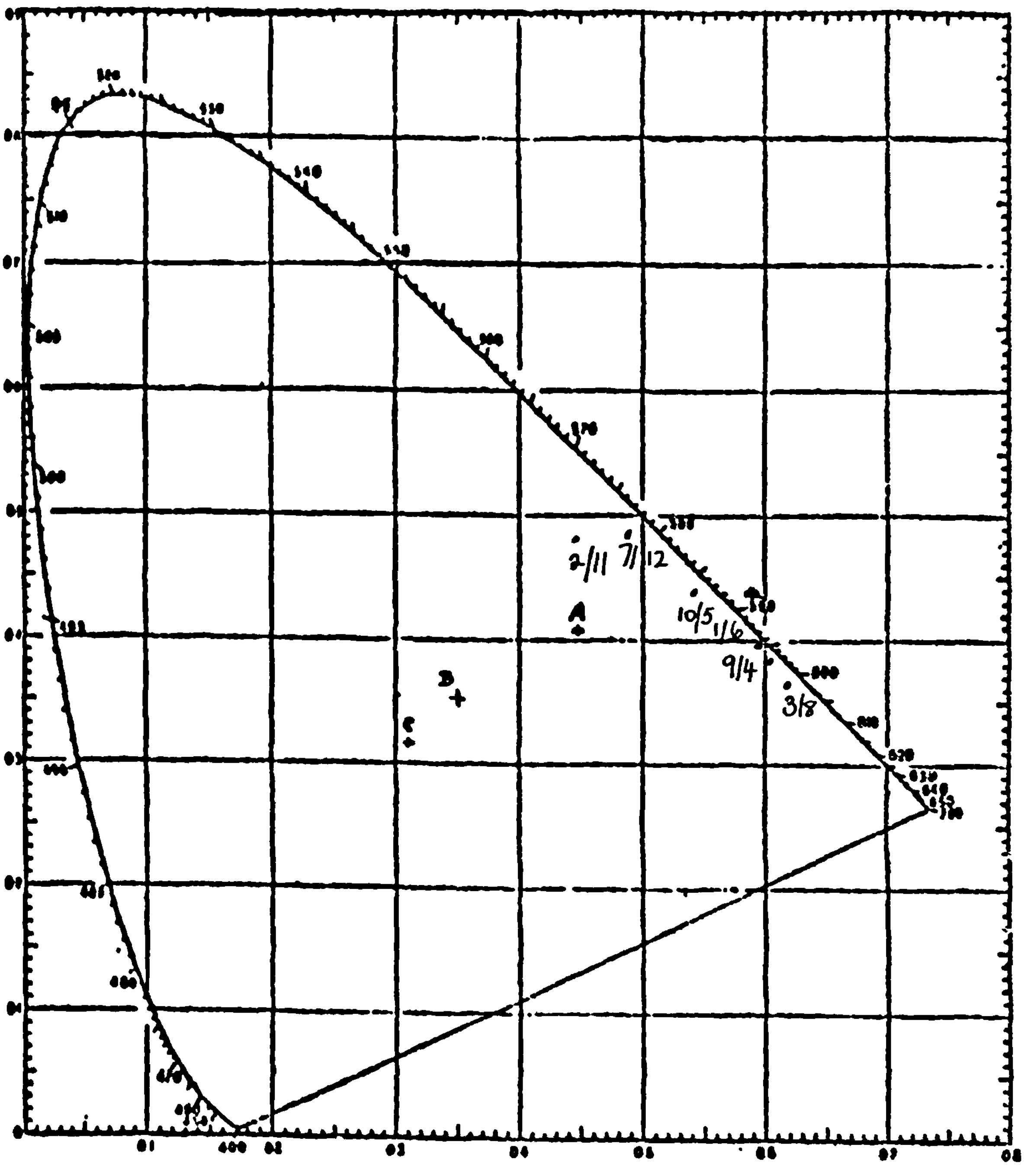
(nine deuteranopes, six deuteranomalous, three protanopes, six protanomalous and a tritanope) and five colour normals, took part in the trial. All observers were under forty-five years of age. They were presented with the bottles in a colour matching cabinet (illuminant provided by lamps which approximated to illuminant C chromaticity co-ordinates of source x = 0.321, y = 0.352, at a uniform level of 500 lux) which was painted a medium grey throughout. The observers were asked to pair up identical samples, holding the bottles at eye-level to make their judgement. A note was made of the samples which had been paired and the task was repeated twice after the bottles had been randomised. A simple score out of six was obtained by noting which samples had been incorrectly paired. A score 6/6 indicates that all were correctly paired, 4/6 indicates that one pair was incorrect etc.

Results

The scores and numbers of incorrect pairs are given in Tables 4 to 8 . Repeated confusions (i.e. oils incorrectly paired by at least one observer (on at least three occasions) are noted in Table 9 , with the chromaticity values of the oils involved. It is evident that deuteranopic observers made the greatest number of repeated confusions, and the errors made by the deuteranomalous observers were similar. The protan observers confused the same pairs of oils as the deutans, but on fewer occasions, and these were not confusion loci for both deuteranopes and protanopes. It is interesting that virtually no errors were made between pairs 2/11 and 7/12 which do not lie along loci.

All groups of colour defective observers made approximately the same number of errors, and the colour normals made few errors in pairing up the oils. The one tritanope was reasonably able to perform the task correctly. It is evident from these results that protan and deutan colour defective observers have considerable difficulty in a task of this nature, and the results can be projected to some extent to infer that difficulties would be experienced by persons with abnormal colour vision working in the oil industry.

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 5 Chromaticity Diagram showing x,y co-ordinates of coloured oils used in oil trial.

Oil Trial

No.	Number Correct out of 6			Incorrect Pairs		
	1stScore	2nd Score	3rd Score	1st attempt	2nd attempt	3rd attempt
D58	4	2	6	10/6,1/5	6/10,3/7,1/5,8/12	-
D36	6	3	2	-	1/4,3/9,8/6	4/8,3/9,10/1,16/5
D61	4	2	4	8/12,7/3	8/12,3/7,5/4,9/10	5/6,1/10
D69	6	4	4	-	5/6,1/10	3/9,8/4
D48	4	6	3	2/12,11/7	-	3/4,8/9,9/1
D49	4	6	6	3/9,8/4	-	-
D41	4	6	3	3/5,10/8	-	9/1,6/4.8/10
D46	2	0	3	5/1,6/8,3/9,4/10	1/10,8/9,5/6,7/11 3/4,2/12	9/3,4/6,1/8
D52	4	6	4	9/8,3/4	-	3/4,8/9
D64	4	2	4	4/3,9/8	6/10,9/8,4/3,1/5	3/4,9/8
D55	4	4	4	3/12,7/8	3/7,8/12	5/6,1/10
D63	3	3	3	3/6,8/10,1/5	3/10,1/8,5/6	8/10,3/1,4/5
D40	2	2	3	8/6,1/5,4/3,9/10	1/8,6/5,10/9,3/4	1/8,9/6,4/3
D34	4	6	6	8/9,4/3	-	-
D47	3	6	4	10/1,12/7,5/6	-	3/7,12/8
D44	2	2	6	4/3,5/1,4/6,8/10	3/4,5/1,6/8,9/10	-

Table 4 Coloured oils - confusions made by Deuteranomalous Observers

No.	Number Correct out of 6			Incorrect Pairs		
	Score 1st	Score 2nd	Score 3rd	1st attempt	2nd attempt	3rd attempt
P21	4	4	6	5/1 , 6/10	6/10, 5/1	-
P19	4	4	4	6/10, 1/5	11/12, 7/2	7/2 ,12/11
P23	4	0	3	1/5 , 6/10	6 /4 , 9/10 5/1 ,11/2 3/12, 7/8	4/5 ,10/7 9/10
P22	4	6	2	12/8 , 7/3	-	10/6 , 7/8 5/1 ,12/3
P24	4	2	2	4/1 , 6/9	9/8 , 3/4 2/12,11/7	6/10, 5/9 4/3 , 8/1
P16	4	2		1/5 ,10/6	5/4 , 3/7 9/10,12/8	

Table 5 Coloured oils - confusions made by protanomalous Observers

	Number Correct out of 6			Incorrect Pairs		
No.	Score	Score	Score	1st attempt	2nd attempt	3rd attempt
P 9	0	6	4	8/9 , 7/2 1/10,11/12 6/5 , 3/4	-	3/4 , 9/8
P 2	4	4	6	6/5 , 1/10	5/1 ,10/6	-
P 7	6	2	4	-	7/3 , 8/12 6/10, 5/1	9/5 , 4/10

Table 6 Coloured oils - confusions made by Protanopes

	Number Correct out of 6			Incorrect Pairs		
No.	Score 1st	Score 2nd	Score 3rd	1st attempt	2nd attempt	3rd attempt
D11	6	2	4	-	6/5 , 7/3 8/12, 1/10	5/1 , 10/6
D20	2	4	3	7/12,10/3 8/1 , 6/5	1/10, 6/5	6/3 , 1/10 5/8
D26	2	3	3	5/1 , 6/10 3/12	5/6 , 9/10 1/4	1/9 , 5/6 10/4
D 1	4	3	4	1/5 ,10/6	10/4 , 5/1 6/9	8/4 , 3/9
D19	4	4	6	9/8 , 3/4	9/8 , 4/3	-
D23	6	3	4	-	1/5 , 4/10 6/8	9/10, 5/4
D30	3	4	2	5/9 , 4/6 10/1	6/10, 1/5	8/9 , 6/10 5/1 , 3/4
D 4	4	2	2	6/10, 1/5	10/6 , 9/8 1/5 , 3/4	1/10, 5/4 9/6 ,
D 3	4			3/12, 8/7		

Table 7 Coloured oils - confusions made by deuteranopes

Number Correct out of 6			Incorrect Pairs		
Score 1st	Score 2nd	Score 3rd	1st attempt	2nd attempt	3rd attempt
6	6	6	-	-	-
6	6	6	-	-	-
4	6	6	6/5 , 1/10	-	-
4	4	4	1/9 , 4/6	1/9 , 4/6	5/6 , 1/10
4	6	6	6/5 , 1/10	-	-

Table Colour oils - confusions made by Colour Normals

Number Correct out of 6			Incorrect Pairs		
Score 1st	Score 2nd	Score 3rd	1st attempt	2nd attempt	3rd attempt
6	6	3	-	-	9/8 , 4/7 , 3/4

Table 8 Coloured oils - confusions made by one tritanope

Colour Vision Defect (No of observers affected given in brackets.)	Repeated confusions made (more than twice by one observer) (No of times given in brackets)	x,y chromaticities of confusion	
		x	y
D (6)	Between pairs 5/10 1/6 (25 confusions)	0.5640 0.6034	0.4200 0.3903
D (4)	Between pairs 9/4 3/8 (11 confusions)	0.6061 0.6298	0.3897 0.3670
DA (1)	Between pairs 5/10 1/6 (7 confusions)	0.5640 0.6034	0.4200 0.3903
DA (2)	Between pairs 9/4 3/8 (9 confusions)	0.6061 0.6298	0.3897 0.3670

Table 9 Repeated confusions made by all colour defectives at the oil trial.

sufficient to qualify them to be entered in the column.
The total number of times that the confusions were made by each group is given below:

	Colour Vision Defect			
	D	DA	P	PA
Confusion between pairs 5/10 and 1/6	26	21	8	12
Confusion between pairs 9/4 and 3/8	7	28	4	2

The average scores for all observers are given below in Table 10 .

Colour Vision Defect (no of observers in brackets)	Average Score out of 6
D (9)	3.5
DA (16)	4
P (3)	4
PA (6)	3
Colour Normals (5)	5.5

Table 10 Average Error scores for all observers at Oil Trial.

The confusions between pairs 5/10 and 6/1 and pairs 9/4 and 3/8 is to be expected because these colours lie along confusion lines.

IV.2 MEAT TRIAL

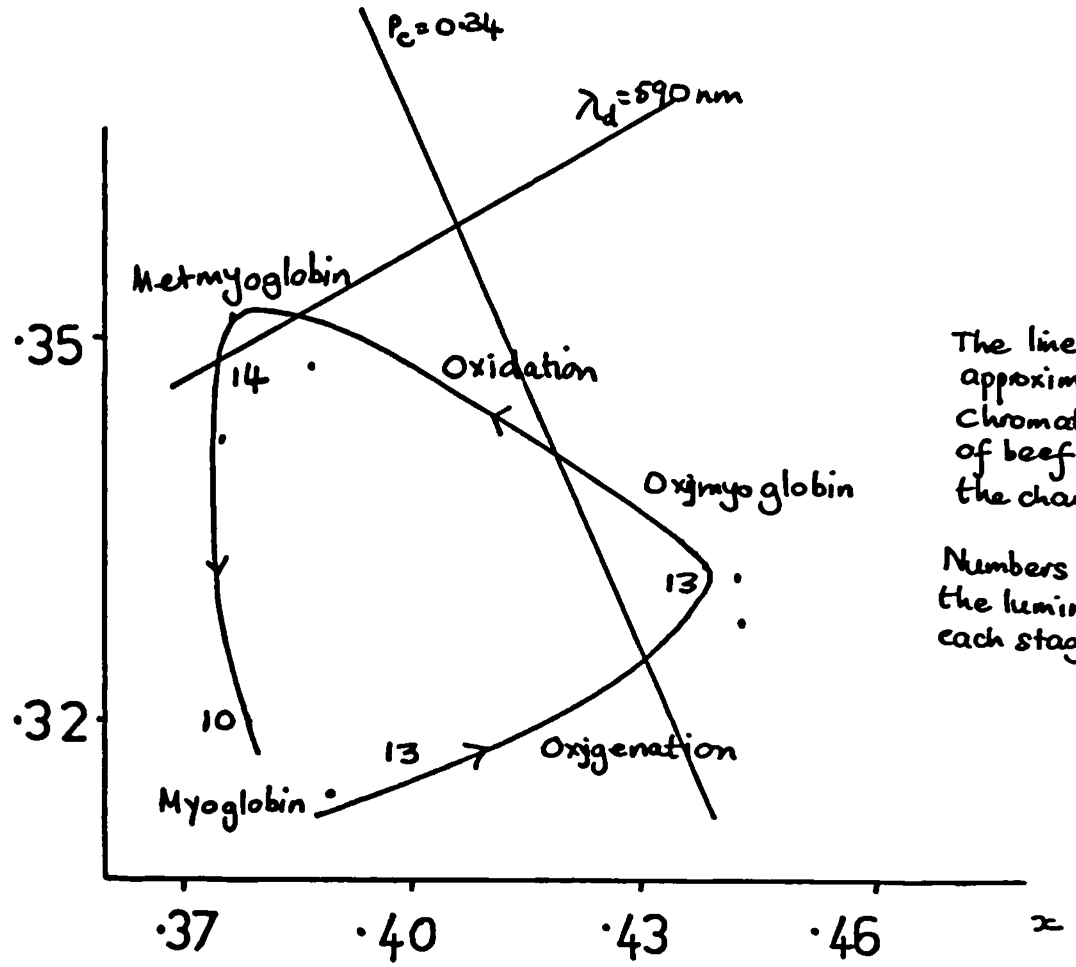
Introduction - Colours of Meat

Fresh and cooked meats predominate in the red/brown colour range - colours which frequently cause difficulties to colour defective observers.

The dull red surface of freshly cut beef brightens on exposure to oxygen as the result of the formation of oxymyoglobin, with storage this bright red colour pales and turns brown as metmyoglobin is formed in the tissues. Under conditions of reduced oxygen pressure e.g. storage in an air-permeable wrapper, the metmyoglobin reduces back to myoglobin. The colour changes observed during this process have been described by HUTCHINGS (1969) and are shown in fig. 6 . Hutchings notes that the point at which fresh raw beef becomes unacceptable on storage is clearly defined by the x(red) chromaticity value. Upon oxidation the red oxymyoglobin changes to the brown metmyoglobin and the point at which this can be detected corresponds to a value of $x = 0.420$.

It is evident that colour discrimination plays an important role in the recognition of meats for inspection purposes. It appears that Public Health Inspectors and those who sit on Meat Inspection Examining Boards are not screened for

FIG 6



The line is the approximate chromaticity locus of beef undergoing the changes described.

Numbers indicate the luminances at each stage

COLOUR OF RAWBEEF AFTER HUTCHINGS 1969

defective colour vision[1].

The Trial

A task to investigate the ability of colour defective observers and a group of colour normal controls, at detecting small differences in the colours of prepared luncheon meats, was designed in co-operation with Miss J Grant of the Food Industries' Research Association. The samples, which contained different amounts of pigment additives, showed small colour differences, but over the entire range the differences were quite considerable. A total of twenty-six samples were used, forming eleven different pairs. For two of the pairs four exactly similar samples were produced. The samples were presented to the observers in a random assortment in a colour matching cabinet (illuminant C 400-500 lux) with the request that they pair up like samples. No other clues were given except to explain that there were two specimens of each sort in the pile, and they were asked to use colour as their main criterion for pairing.

Twenty-four colour defective observers (five deuteranopes, twelve deuteranomalous, three protanopes and four protanomalous) and fourteen colour normals took part in the trial. The entire investigation took place on one day only because of possible colour changes of the samples with age.

1. Personal communication with Dr. A. McDonald of the Meat Research Institute, Somerset.

The number of errors made in pairing up the twenty-six samples into eleven different pairs, a total of thirteen actual pairs, together with the types of confusions made are given in Tables 11 to 14 . The samples were coded to facilitate identification to the examiner. The errors made are grouped into those which are significant (pink samples matched with red samples) and those which are less significant (pink samples matched with medium coloured samples and red samples matched with medium coloured samples). The grouping into red, medium and pink samples, and their corresponding colorimetric values are shown in Table 16 .

Colorimetric Measurements of Luncheon Meats

Colorimetric measurements were made with a number of different instruments. The Gardiner digital colorimeter was used[1] to obtain Hunter 1942 L.a.b. values, shown in Table 16 . The Model XL10 was used and the standard tomato tile was set at values L = 31.1, a = 29.2 and b = 17.2 for these measurements. The most important value in these readings is the value which is a measure of the degree of redness. Panel assessments[2] showed that a value of between 8 and 11 were the most reasonably acceptable values for luncheon meats. Below a value of 8 the sample was considered too pale, above 11 it was judged as too pink. The "ideal" luncheon meat colour

1. Measurements made by Miss J Grant at the Food Industries Research Association, Leatherhead.

2. Conducted by Miss J. Grant.

(samples 7 and 3) had values L = 63.7, a = 9.2, b = 10.2

Spectral reflectance curves

Spectral reflectance curves of the samples were obtained using a Beckman grating spectrophotometer, by courtesy of PIRA. A sample curve is presented in Figure 67. C.I.E. co-ordinates (x,y and u,v) were obtained for all samples as shown in Table 16. These are plotted in Figure 7.

The average value C.I.E. values for a luncheon meat are x = 0.369. Commercial luncheon meats vary in their C.I.E. y = 0.347

values from x = 0.361 to 0.375.
y = 0.325 to 0.340

Spectral reflectance curves were also obtained at The City University with the Bausch & Lomb Spectronic Spectrophotometer.

Factors affecting overall colour appearance of luncheon meats

1. Different concentrations of dye
2. Fading
3. Fat particle size

In the samples used fading of the colour was reduced by vacuum packing, as fading occurs more readily in the presence of light and air. When not in use the samples were kept in a black bag and refrigerated. The fat particle size of the samples used was the same in each case.

Results and Conclusions

Colour Normals

Fourteen colour normal observers performed the task once only. Their results varied from no errors (five observers) to five errors (two observers) and are given below:

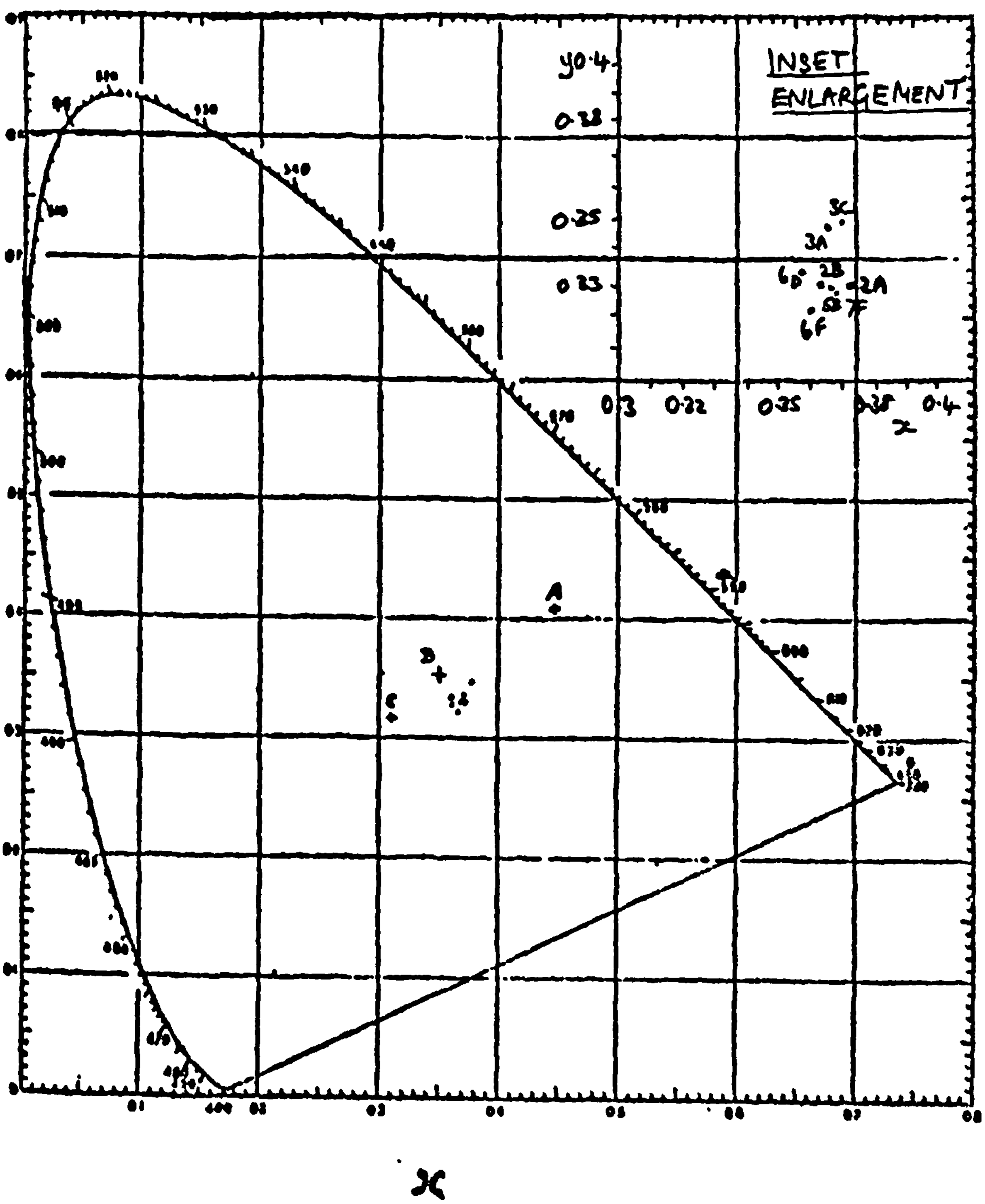
5,0,0,5,2,2,3,4,2,2,0,4,0,0,

Average two errors perperson.

Colour defectives

The most common confusions made in pairing the luncheon meat samples are shown in Table 15 . The protanomalous observers made more errors than the protanopes and most of the errors made by the former group were in the 'insignificant' category. The deuteranopes made proportionately more errors than the deuteranomalous observers but most of these were in the 'insignificant' category (i.e. medium coloured samples were matched with red or pink). The deuteranopes rarely matched samples with a red bias with those of a pink bias. Although the total number of "significant" errors made by the deuteranomalous observers is greater than for the deuteranopic group, the "significant" errors made per person is only slightly greater. The error scores given for each attempt show that the deutans made more errors than the colour normals who performed the task. The luminance values for the samples are shown in Table 16 and are found to be similar for all samples. Itis reasonable, therefore, to assume that the errors made by the colour defectives result from their inability to differentiate between the sample hues.

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

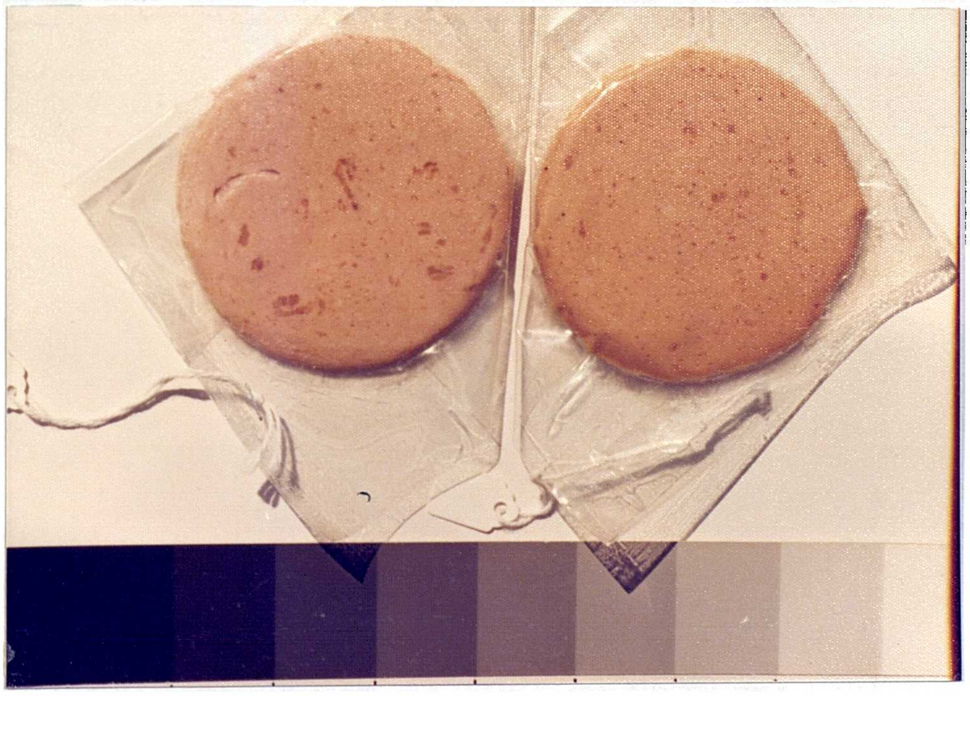
Figure 7 Chromaticity co-ordinates of Luncheon Meats used in Meat Trial

No	Errors				Significant Errors	Less Significant Errors	
	1st	2nd	3rd	Av	Pink samples matched with Red	Med. matched with Red	Med. matched with Pink
	Attempts						
D10	6			6	2B/5A 3C/2B	3A/3C 5A/7F	
D26	2	2	2	2		3C/5B 3C/5B 3A/3C 3A/3C	2B/5B 2B/5B
D26	2	2	2	2		3C/5B 3C/3A 3C/5B 3C/3A	5B/2B
D11	4	0	5	3		3A/3C 3A/3C	3A/2A 2C/2A
D27	7			7	3C/2B	7F/6F 3C/5B 3C/5B	2C/2B 3A/2A

Table 11 To show colour confusions/matches made by deuteranopic observers for Luncheon Meat Trial

Food Trial

Luncheon meat samples used



Two dissimilar samples

No	Errors 1st Attempts	Errors 2nd Attempts	Errors 3rd Attempts	Av	Significant Errors Pink samples matched with Red	Less Significant Errors Med matched with Red	Less Significant Errors Med matched with Pink
P12	2	2	2	2			3A/6D 3A/6D
P 7	3	0	0	1			5B/3A 2B/3A
P 2	0	0	0	0			

Table 12 To show colour confusion/matches made by Protanopic observers for Luncheon Meat Trial

No	Errors 1st	2nd	3rd	Av	Significant Errors Pink samples matched with red	Less Significant Errors Med matched with Red	Med matched with Pink
	Attempts						
D34	4	4	4	4	3C/2B	3C/7F	
D44	4	0	4	3	2B/3C	3A/3C 3A/6F	2B/3A
D46	2	2	-	2	2B/3C 2B/3C 2B/3C		
D49	2	3	2	2		all insignificant	
D52	3	4	2	3	2B/3C		
D55	4	6	0	3	2B/3C 2B/3C	3A/3C	
D58	2	0	0	1		3A/3C 3A/3C	
D60	2	5	3	3	2B/6F	7F/6F	7F/2B 7F/2B
D61	0	0	0	0			
D67	2	-	-	2	2B/3C 2B/3C		
D68	7	2	2	4	2B/3C 2B/3C	6F/3A	3A/2B
D70	6	2	2	3	2B/3C		2C/6D 2C/6D

Table13 To show colour confusions/matches made by deuteranomalous observers for Luncheon Meat Trial

No	Errors 1st	2nd	3rd	Av	Significant Errors Pink sample matched with Red	Less Significant Errors Med matched with Red	Med matched with Pink
	Attempt						
P23	3	4	5	4	2B/6F 2B/6F	6F/3A 3A/3C 3A/3C /A/3C 6F/3A	3A/5B 2B/5B
P22	0	3	0	1		3C/3A 3C/5B	5B/3A
P19	2	2	–	2	3C/2B 3C/2B		
P16	3	2	-	2	3C/2A 3C/2A		

Table 14 To show colour confusions/matches made by Protanomalous observers for Luncheon Meat Trial

COLOUR VISION DEFECT and number of observers		SIGNIFICANT ERRORS and number of times confusion was made		LESS SIGNIFICANT ERRORS			
				Medium matched with Red		Medium matched with Pink	
DA	(12)	3C/2B	(13)	3A/3C	(4)	3A/2B	(2)
				3A/6F	(2)	7F/2B	(2)
						2C/2D	(2)
D	(5)	3C/2B	(2)	3A/3C	(6)	2B/5B	(3)
				3C/5B	(6)	3A/2A	(3)
PA	(4)	3C/2A	(2)	3A/3C	(4)	5B/3A	(2)
P	(3)	-		-		3A/6D	(2)

TABLE 15 MOST COMMON CONFUSIONS IN PAIRING LUNCHEON MEATS MADE BY COLOUR DEFECTIVES.

CODE NUMBERS OF SAMPLES		HUNTER L.a.b. VALUES			C.I.E. CHROMATICITY VALUES		
		L	a	b	x	y	Y
2A	5/10	69.4	4.3	21.1	0.373	0.330	35.94
2B	32/38/12/27	71.0	6.2	19.4	0.363	0.332	34.85
6D	23/25	49.5	6.7	6.9	0.358	0.335	40.66
5B	18/20	60.9	8.6	7.3	0.366	0.333	33.24
7F	2/9	65.3	10.3	9.1	0.368	0.330	34.97
3A	5/11	64.8	11.5	9.6	0.366	0.347	35.63
2C	16/30	69.4	11.7	17.0			
6F	8/4	63.7	12.5	7.9	0.362	0.323	36.36
5A	24/28/19/21	58.5	14.5	5.9			
3C	13/14	66.9	18.4	6.6	0.372	0.347	32.05

TABLE 16 TO SHOW HUNTER 1942 L,a.b. VALUES AND C.I.E. x, y and u, v, CHROMATICITY CO-ORDINATES OF LUNCHEON MEATS USED IN TRIAL IN INCREASING ORDER OF REDNESS (a VALUE).

IV.3 ELECTRIAL TRIAL

Introduction and aims

The trial was conducted to see how well colour defective observers performed at a colour naming task related to a practical situation. The task involved the colour naming of the coloured uniform bands painted on a coloured background of electrical resistors and capacitors. The ability of colour defective observers to identify correctly the value of a resistor or capacitor using a colour code was thus examined. In addition, observers were asked to give the colour names to coloured wires and to form pairs with the two identical wires present in a random selection of eighty wires, forming forty pairs.

Thus an attempt has been made in this trial to simulate the conditions of an electronics technician/engineer, and the numerous jobs involving coloured wiring.

The ability of colour defectives to perform these tasks was related to their performanee on standard colour vision tests, and also to the performance of a group of colour normals who performed the tasks.

Previous Work

1. Resistor identification by colour defective observers

HARDY, RAND AND RITLER (1954) mention preliminary findings on the performance of colour defective observers at identifying the colour code of resistors and their rating on the H.R.R. plates. They concluded that from the standpoint of vocational selection and guidance further study was needed to show whether agreement could be established between quantitative ratings given by a general colour vision test, such as the H.R.R. plates, and the colour vision requirements of specific colour tasks which involve the use of surface colours. In their experience those colour defective observers classified as "mild" on the H.R.R. plates could read the colour code as well as colour normal observers at normal room illumination.

The authors also made a brief study of the performance of colour defective observers at matching coloured wires. Their preliminary findings led them to conclude that the matching up of coloured wires seemed to be less difficult for most colour defective observers than naming the bands of colour-coded resistors. Two attempts to obtain further details of this American study, by correspondence with Catherine Ritler, have been unsuccessful.

A most comprehensive study on the recognition of colour codes of resistors by normal and colour defective observers, at several illumination levels, was carried out by WALRAVEN AND LEEBECK (1958 and 1960). Their results are correlated with subject performance on the H.R.R. plates and the Ishihara test, and confirm the results of HARDY, RAND AND RITLER (1954).

They reached the following conclusions:

1. That some colour defective observers can read the colour codes of resistors as well as normal people under usual illumination conditions.
2. For personnel dealing with electronics work those classified as mild on the H.R.R. plates should be passed for employment, but those classified as having medium or strong defects must be refused employment.

The authors stressed that conclusion two holds good only under "normal" conditions of illumination. It was found that if the condition for selection would have been that colour defectives should recognise colours as well as normal observers it would have been "impossible ever to pass one."

In the study by Walraven and Leebeck sixty-nine different resistors each having three code rings, were presented to the observers one by one. The observer was required to write down the names of the code rings choosing his colours from ten different colour descriptions - black, brown, red, orange, yellow, green, blue, purple, grey and white. The choice of colours was shown prior to the test and the colour names were also indicated. No time limit was imposed and no cross-references between resistors was easily possible. The task was conducted under several illumination levels - 400, 40, 3.8, 0.6, 0.18 lux and the type used was tungsten, illuminant A. The total number of presentations was two hundred and seven; the number of times each colour was presented was:

black	19	yellow	18
brown	36	green	19
red	41	blue	10
orange	30	purple	11
grey	17	white	6

The interpretation of results was made by correlating the number of errors with the classification according to the H.R.R. plates and the Ishihara test, for different levels of illumination, and an investigation of the type of mistakes made.

Summary of results obtained by Walraven and Leebeck 1958

Fifty-seven colour defective observers (nineteen mild, twelve medium and twentysix strong, according to the H.R.R. classification) and twentyfour colour normal observers carried out the test at 500 lux. Of those colour defectives who made less than ten errors (that is as good as colour normals) seventy-five percent were classified as mild by the H.R.R. plates. Those colour defectives who obtained a fifty percent failure on the Ishihara plates (16/36 mistakes) made as few mistakes at the resistor task as the colour normals.

The authors concluded that the H.R.R. plates were more efficient for the selection among colour defective observers than the Ishihara test.

Thirty-five colour defective observers and eight colour normals carried out the test at the five illumination levels. The number of errors as a function of the level of illumination for each group of colour defectives were shown, and the average percentage errors for each group were also documented. It was found that the mean mild colour defective observer made as many mistakes as the mean normal colour observer at any intensity six times lower. When the illumination level is reduced by a factor of 5.6 for a normal then the latter will make as many errors as the observer classified as mildly defective on the H.R.R. plates would have made at the original illumination level. The factor was found to be 16 for medium observers (deuteranomalous) and 60 for strong deutans. Slight differences were found for the protan observers. It was not possible for the authors to make a general statement concerning the one mild protan observer because of the small sample. However, the corresponding factor for the medium protan observers was found to be 20 and 500 for strong protans.

These findings show the importance of maintaining good illumination levels for those concerned with resistor and capacitor identification, even for those with normal colour vision.

A brief study was made by VON G. RICKLEFS AND WENDE (1966) to see whether or not colour defective observers could reliably perform a job as electronics technician. Twenty-six colour-coded resistors were presented to twenty colour defective observers (five deuteranomalous, three protanomalous, eleven deuteranopes and one protanope) in a manner similar to the method used by Walraven and Leebeck. The authors found that none of the colour defectives could recognise the colour-code correctly and seven observers did not recognise more than fifty percent of all resistors. Only three observers could recognise more than two-thirds of all resistors used. The authors concluded that colour defective observers could not be employed safely or effectively as radio or T.V. mechanics.

2. Identification of colour-coded wires and cables by colour defective observers.

LAKOWSKI (1968) reports a study made by STEVENS (1962) involving the matching of G.P.O. telephone wires. Sixteen colour defective observers (seven deuteranomalous, one protanomalous, five protanopes and three deuteranopes) and a group of colour normals participated. The test specimens consisted of six pieces of grey perspex with twists of three differently coloured wires. The subject had to match each of the six pieces in turn from a selection of thirty other pieces, six of which were matched to the standards and the rest graded in colour distance from the standard or selected piece. The particular wires chosen and the time taken, provided the basis for rating each subject's performance. The wires (standard) were selected so that they included two which lay along the protan confusion loci, two along the deutan confusion loci, and two along the tritan loci. The source used was illuminant A at 550 lux.

The anomalous trichromats made more errors than the normal group and also took slightly longer. The dichromats "were hopelessly confused, made many mistakes and took much longer". The greatest distinction between groups was between the normals and anomalous trichromats as one group and the dichromats as another group.

This confirms the view of the other authors that mild anomalous trichromats can often cope adequately with an industrial colour task in the electrical industry.

A small study of the performance of anomalous trichromats at identifying colour-coded telecommunication cables, and the relationship between error scores on clinical colour vision tests has recently been carried out in Australia,[1] but few details have been forthcoming. The only information available is that no correlation between the errors at the practical task and the test scores on the Farnsworth-Munsell 100 Hue Test, or the H.R.R. plates has been obtained. The present writer obtained similar results in this study.

1. Personal written communication with Dr. J. Alexander University of New South Wales, Department of Applied Physics and Optometry 2nd March 1976.

IV.3 ELECTRICAL TRIAL

Fifty-five colour defective observers were asked to identify the coloured bands of colour-coded resistors and capacitors, and pair up similarly coloured wires from a selection of wires. Of these, twenty-two were deuteranomalous (DA) sixteen deuteranopic(D), six protanomalous (PA) and eleven protanopic (P).

Seven colour defective observers performed the task twice. Repeat trials were conducted on different days and no indication was given of previous performance.

In addition, thirteen colour normals performed the electrical trials.

Conditions

The task was carried out under controlled illumination in a standard colour matching cabinet, illumination range 400-500 lux, and chromaticity x=0.308, y=0.3519, correlated colour temperature 6,900^{o}K, approximately standard illuminant C.

Observers chose their own working distance. This was found to vary from approximately 10cm - 20cm.

The ages of the colour defective observers ranged from twelve years (12 years) to sixty-five years (65 years) most of them being under fifty years. Four observers were elderly (between sixty-five and seventy years) and two showed signs of acquired blue defects of colour vision, due to marked senile ocular changes, and diabetes melitus in one observer. All other observers were free from obvious ocular pathology.

The task

Resistors

Twenty-seven resistors were used. Initially seven large resistors were presented to the observers, all of them with a dark brown background and 4 coloured bands superimposed. The overall dimensions of the resistors Nos. 1-8 varied from 14 - 18.5 mm length, 5-6mm width with the dimensions of the bands varying from 5-6mm length, and 1-2mm width (see Appendix 7 for details). Twenty smaller resistors (variation of overall dimensions 6-10mm length, 2-4mm width, variation of bands exposed 2-4mm length, 0.5-1mm width), whose background colours varied from green, yellow, red, grey, light and dark brown, each containing four coloured bands, were also used.

Capacitors

Eighteen colour-coded capacitors were also used. Their overall dimensions of bands varied from 10-27mm length and 1-5mm width. Each contained four or five coloured bands but there was no background colour, all bands being juxtaposed, and occupying the entire surface. The bands of the capacitors were significantly larger in overall length and width than those of the resistors (see Appendix 8 for details). By using both resistors and capacitors the effects of the size of the coloured band in the identification could be assessed.

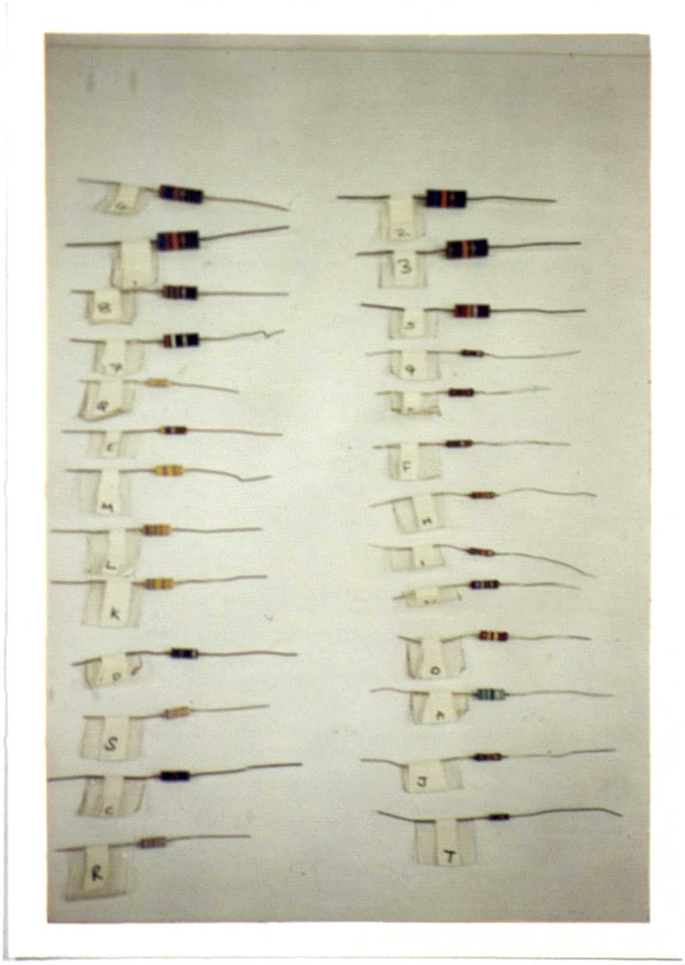
<u>Procedure</u>

All observers carried out the task individually. Each was given a card showing the colour names that could be used for the colour identification of the bands on both resistors and capacitors. The choice of colours was that of the International Code for colours of resistor and capacitor bands as specified by B.S. 1852 (1967) colours, white, black, brown, grey, red, orange, yellow, green, blue, mauve or violet, silver and gold.

No time limit was imposed and the task could be done in any order although observers were advised to identify the larger resistors before attempting the smaller ones which presented greater difficulty. Cross-reference between individual resistors was allowed since the components were presented in a collection and never in isolation.

Electrical Trial

The task in operation



Resistors used

Colorimetric data of resistors and capacitors

Colour values for fixed resistors and capacitors are specified in B.S. 1852 (1967). Details appear in Appendix 7 . The colour system allows an identification of the resistor/capacitor value, tolerance and in certain circumstances the grade of component. The first colour band indicates the first significant figure of value, the second band the second significant value, the third band indicates the multiplier in indices of 10, and the fourth band (if present) indicates the percentage tolerance on the nominal value. If no colour appears in this position the tolerance is ± 20%.

Colorimetric values and Luminance factors are specified by British Standard Institution and these are given in Table 17 .

Colour	B.S. 381C colour no.	Approximate Munsell Ref	C.I.E. values Illum c		Luminance Factor %
			x	y	
Brown	412	5YR 2/4	0.473	0.376	3.2%
Red	538	5R 3.5/16	0.626	0.314	6.8%
Orange	557	2.5YR 6/14	0.556	0.401	24.4%
Yellow	355	2.5Y 8/12	0.488	0.480	50.9%
Green	221	10GY 4/8	0.314	0.519	10.3%
Blue	166	7.5PB3.5/12	0.184	0.156	9.4%
Violet	796	7.5P 3/7	0.289	0.205	6.4%
Grey	632	10B 4/0.5	0.292	0.304	12.2%

All colorimetric values are taken for gloss surfaces. These colorimetric values are plotted on a C.I.E. x,y, chromaticity diagram in Fig.

Table 17 Colorimetric values and Luminance factors for resistor and capacitor codes

Observations

I. It is interesting to note that no specification is given for the background colour which is decided by each individual manufacturer (Bageley Private Communication 1975[1]). No tolerance values for the colour limits are given and this matter has been discussed with technical officers at B.S.I. (Pittard, and Reynolds, private communication 1975). The main reason why tolerance values for resistor and capacitor colours are not specified appears to be due to the following reasons:

1. Manufacturers are limited to a range of pigments which are non-toxic and readily available. Colour tolerance specification would restrict the range of pigments further. Economy is the uppermost consideration.

2. A number of factors affect the colours of resistors and capacitors during their life:

a) soiling

b) fading and discolouration with age due to the non-stability of the pigments used.

c) oxidation with age.

d) elevated temperatures. The pigments tend to scorch at high temperatures and become browner.

3. In the manufacturing process a number of factors affect the final colour of the product.

a) final baking in the process tends to make the colours darker.

1. Mr. Bageley Erie Resistor Company, Great Yarmouth.

b) application of a lacquer as a final coating alters the original colour marginly.

4. Colours are matched visually in the manufacturing situation involving resistors and capacitors. Observations during visits to such establishments reveal that colours are usually matched "so as to look right", to perhaps only one individual, and little care is taken to conform to the B.S. colour specification in any case.

5. The B.S.I. is a recommending body only and there is no legal enforcement of such colour coding. The only B.S. requirement is for resistors "to be legible as determined by visual examination".

II. There is no specification given for wid th of bands or their spacing. These two factors vary considerably even within individual resistors.

All these factors are important in a consideration of the ease of identification by colour defective observers and a full discussion appears in the section 3 dealing with the electrical industry.

Experimental determination of colours of actual paints used for resistor and capacitor bands and wires

The colorimetric characteristics of the bands of resistors and capacitors and the wires used in the trial were investigated to see how closely they agree with the B.S.I. recommendations.

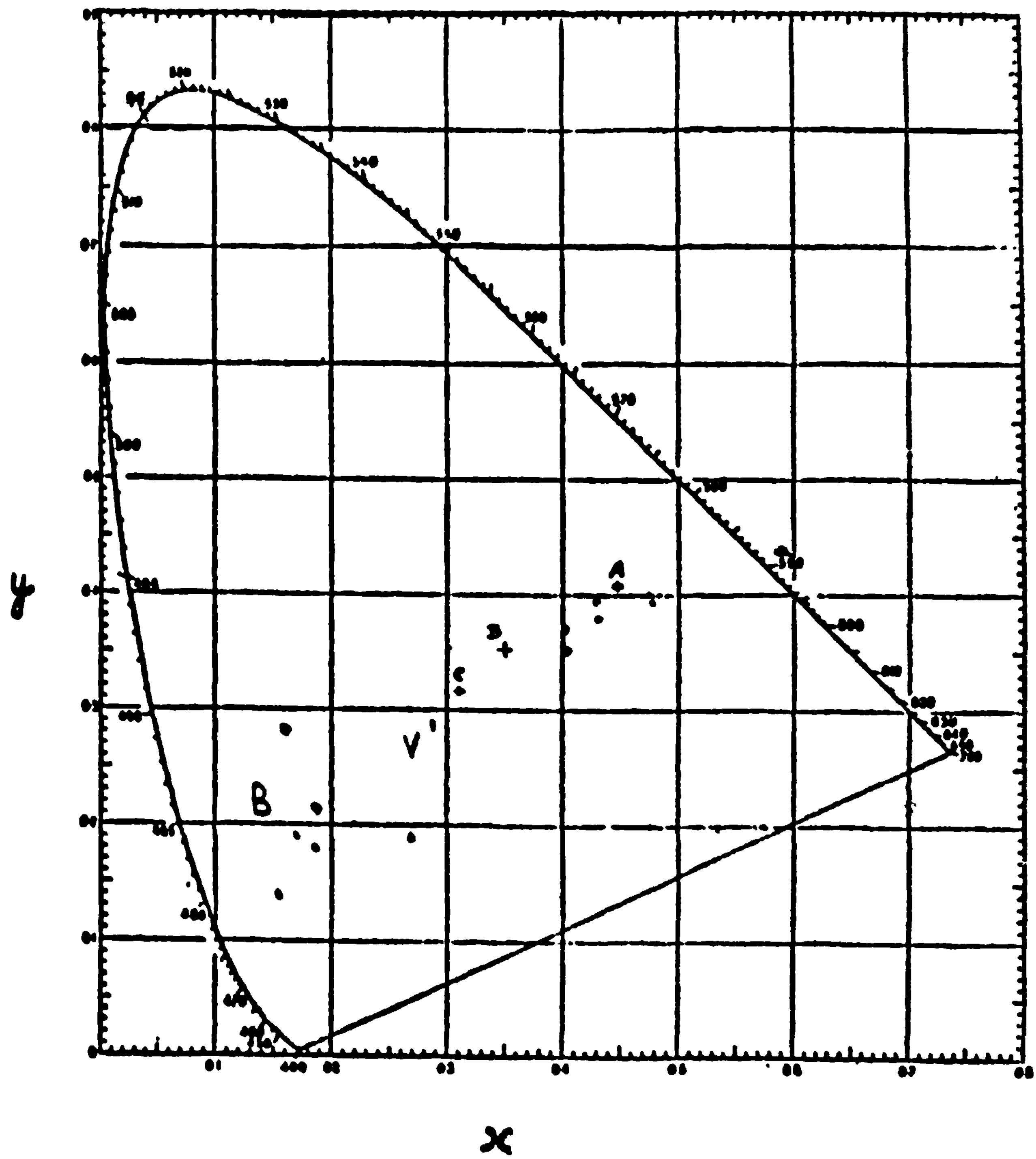
The C.I.E. x,y chromaticity co-ordinates were obtained by a direct visual comparison with the Munsell Book of Colour (under illuminant C) to obtain the Munsell specifications, and these were then converted to C.I.E. x,y co-ordinates using conversion tables. Direct spectrophotometric measurements were not possible because of the size of the bands.

Initially the Munsell Matt Book of Colour was the only edition available and the glossy surface colours of the resistors were compared with the Matt Munsell chips. This was felt to be inadequate as good matches were difficult to make with such a difference in the surface characteristic. However plots of these co-ordinates were made and appear in figure o 8 . Later a Gloss edition of the Munsell Book of Colour became available and the direct visual comparison between the background colours, and the colours of the bands, under illuminant C, was repeated. The plots of these co-ordinates appear in figure 9 . Figure 10 shows the the positions on the C.I.E. x,y diagram of the B.S.I. recommended colours for resistors and capacitors, and a considerable discrepancy occurs between these values and the positions obtained in practice.

Although the experimental determination of the chromaticities of the resistor colours by visual matching with the Munsell Book of Colour was felt to be the best method possible under the circumstances, there is little doubt that the positions of these colours on the C.I.E. chart are subject to errors due to the visual nature of the match, and the difficulty presented by the size of the bands.

It was possible to match some colours very accurately, but a few presented problems and only approximate Munsell specifications (or the nearest Munsell specification) could be given for these colours. Usually several Munsell chips were very close to the colour of the band and in these cases more than one Munsell specification is given for each band.

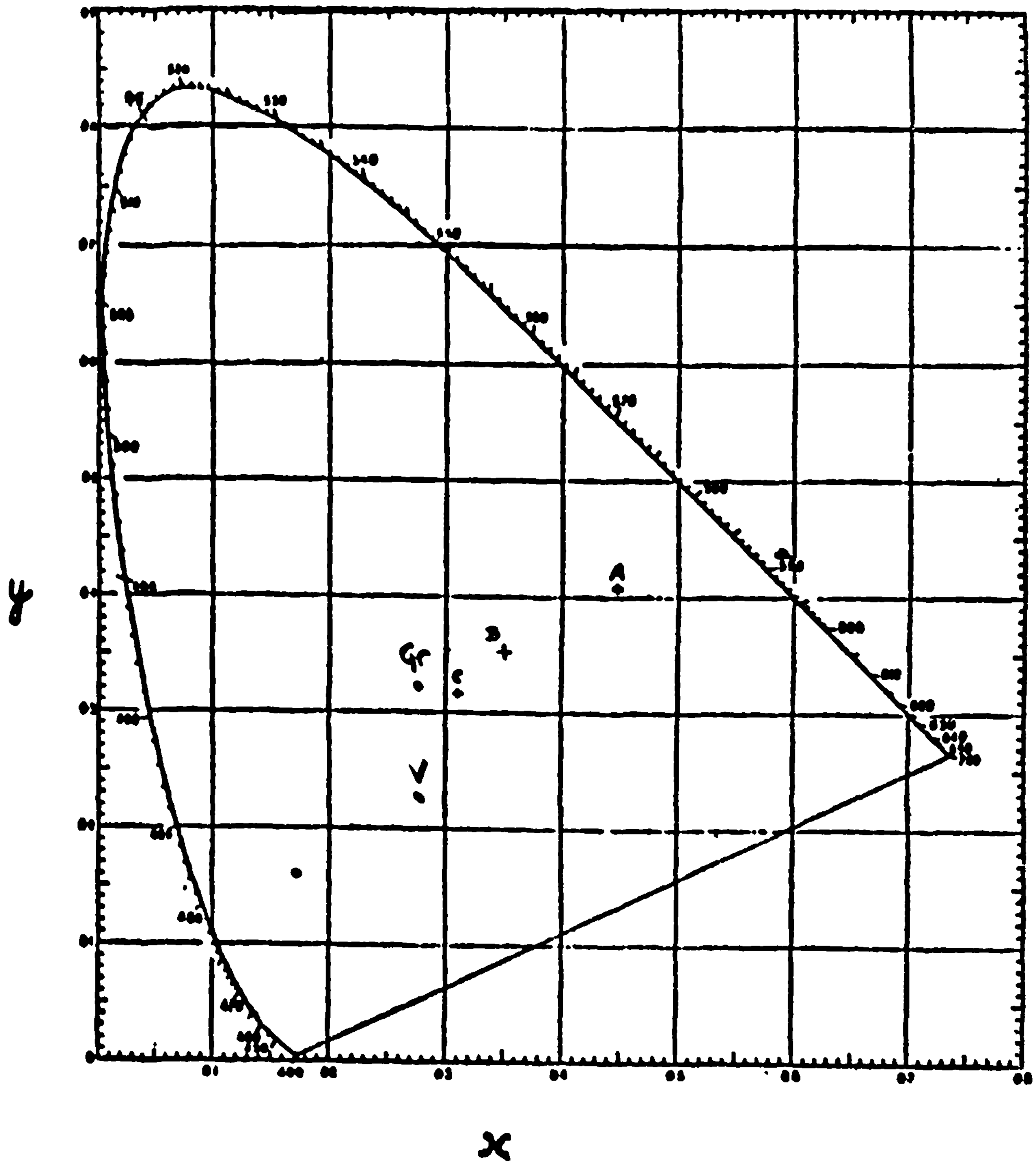
C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 9 Chromaticity plots of resistor bands and background colours of colour coded resistors used in trial.

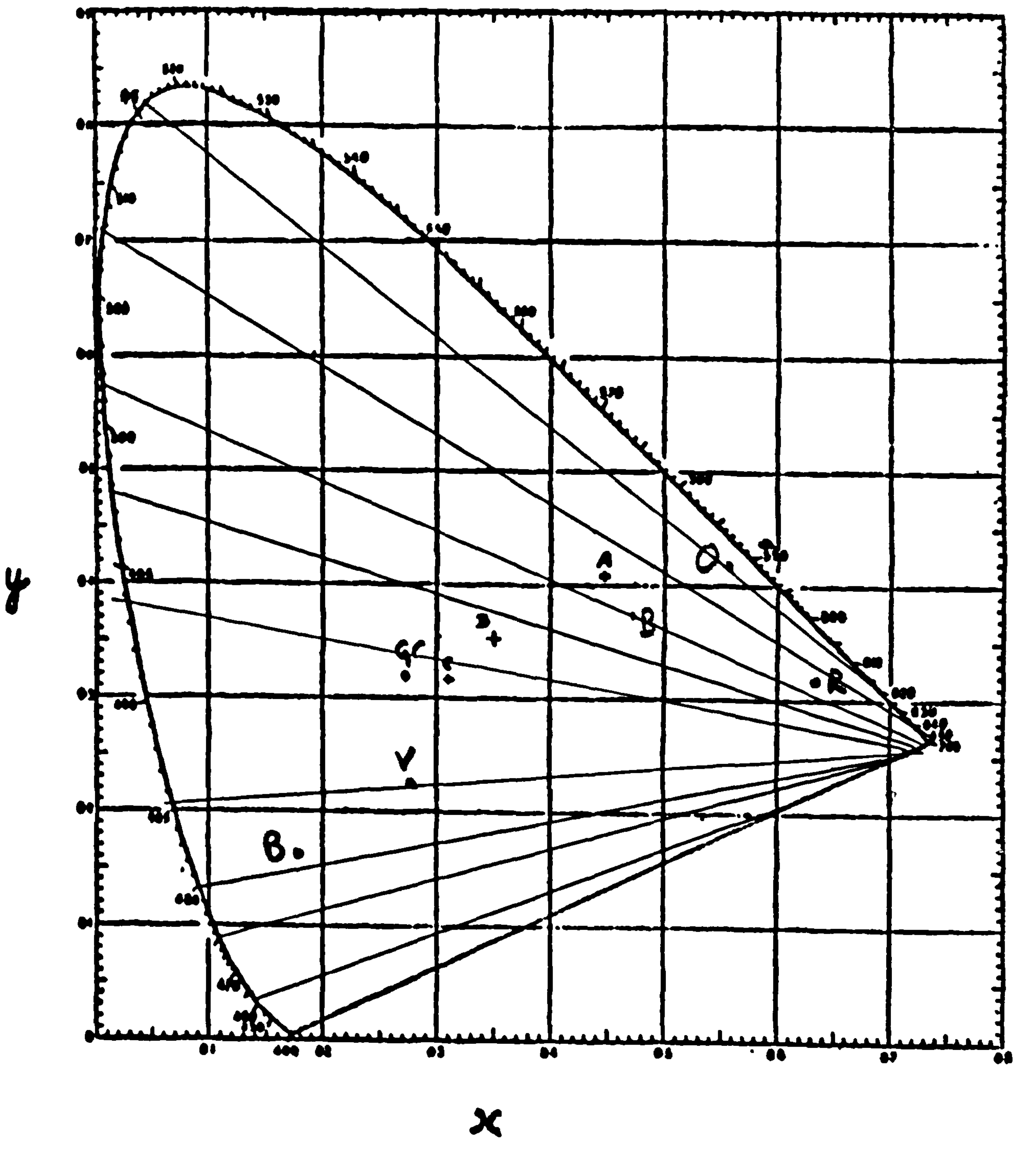
C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 10 Chromaticity plots of Resistor/Capacitor Code as specified by B.S. 318C (1964) Supp No 1 (1966)

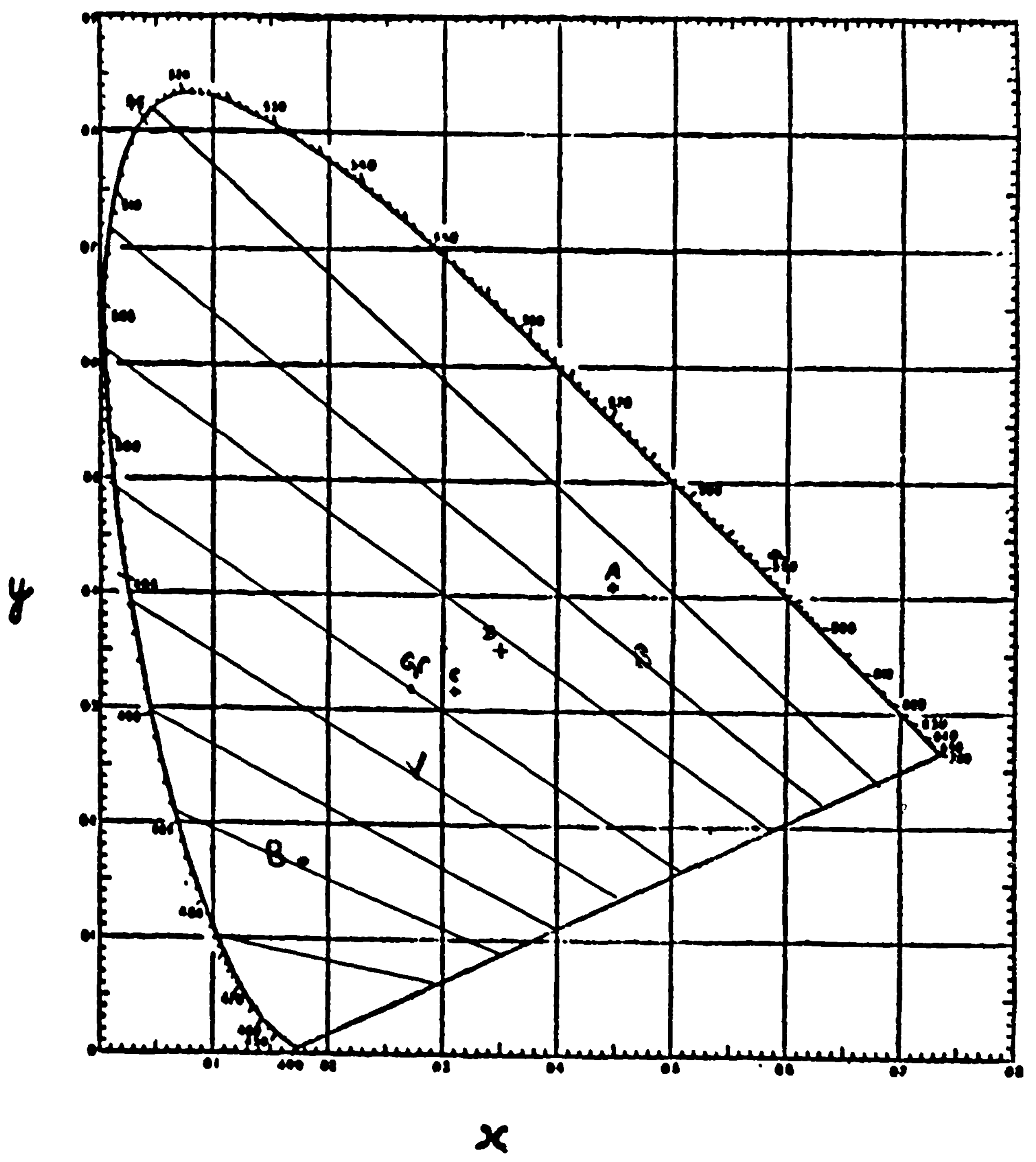
C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 10a Chromaticity plots of Resistor/Capacitor Code as specified by B.S. 318C (1964) Supp No 1 (1966) with protanopic confusion loci.

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 10b Chromaticity plots of Resistor/Capacitor Code as specified by B.S. 318C (1964) Supp No 1 (1966) with deuteranopic confusion loci.

C.I.E. CHROMATICITY CO-ORDINATES

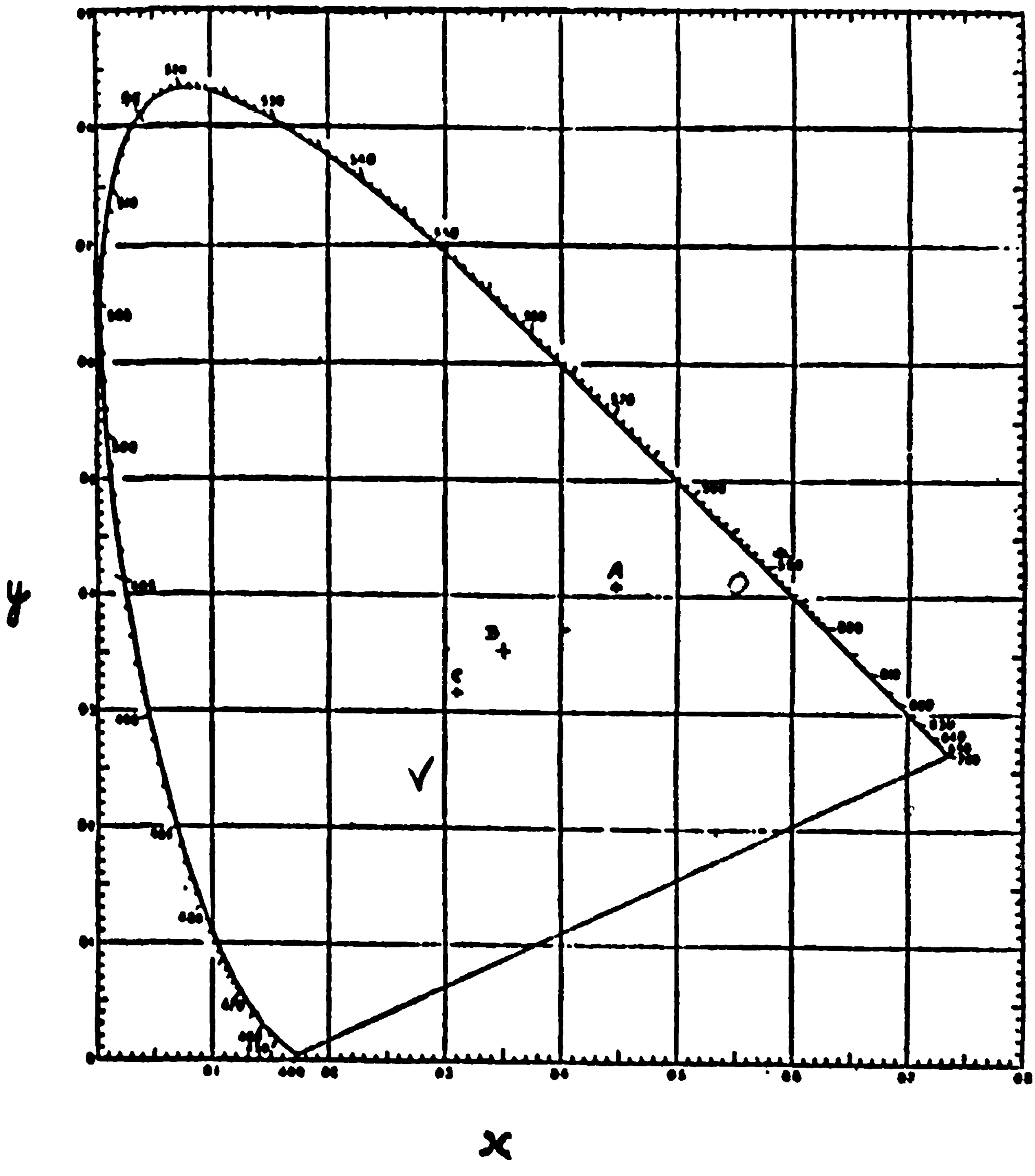
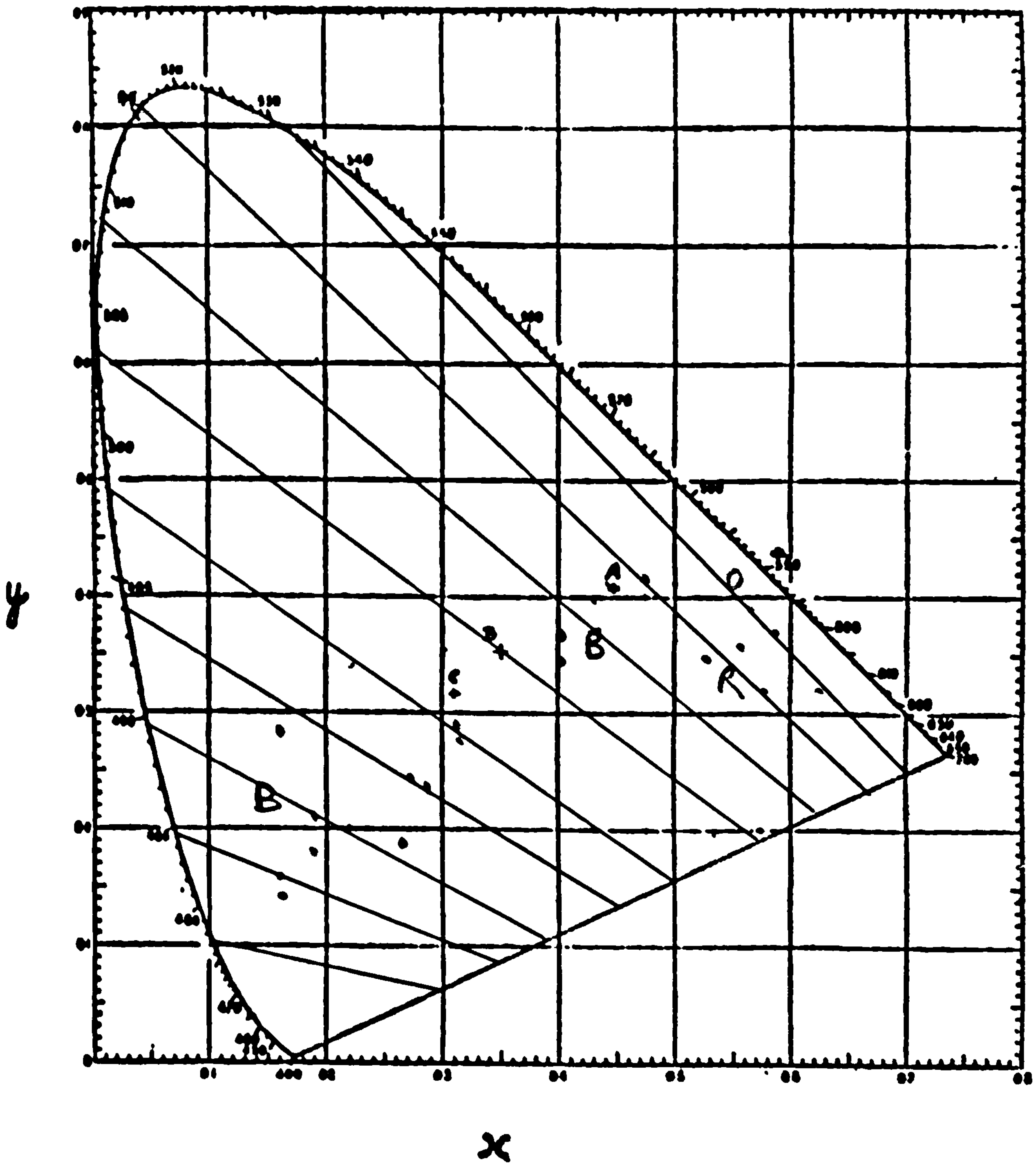


Figure 11 Chromaticity plots of capacitors used in trial.

Wavelength marked in nanometers

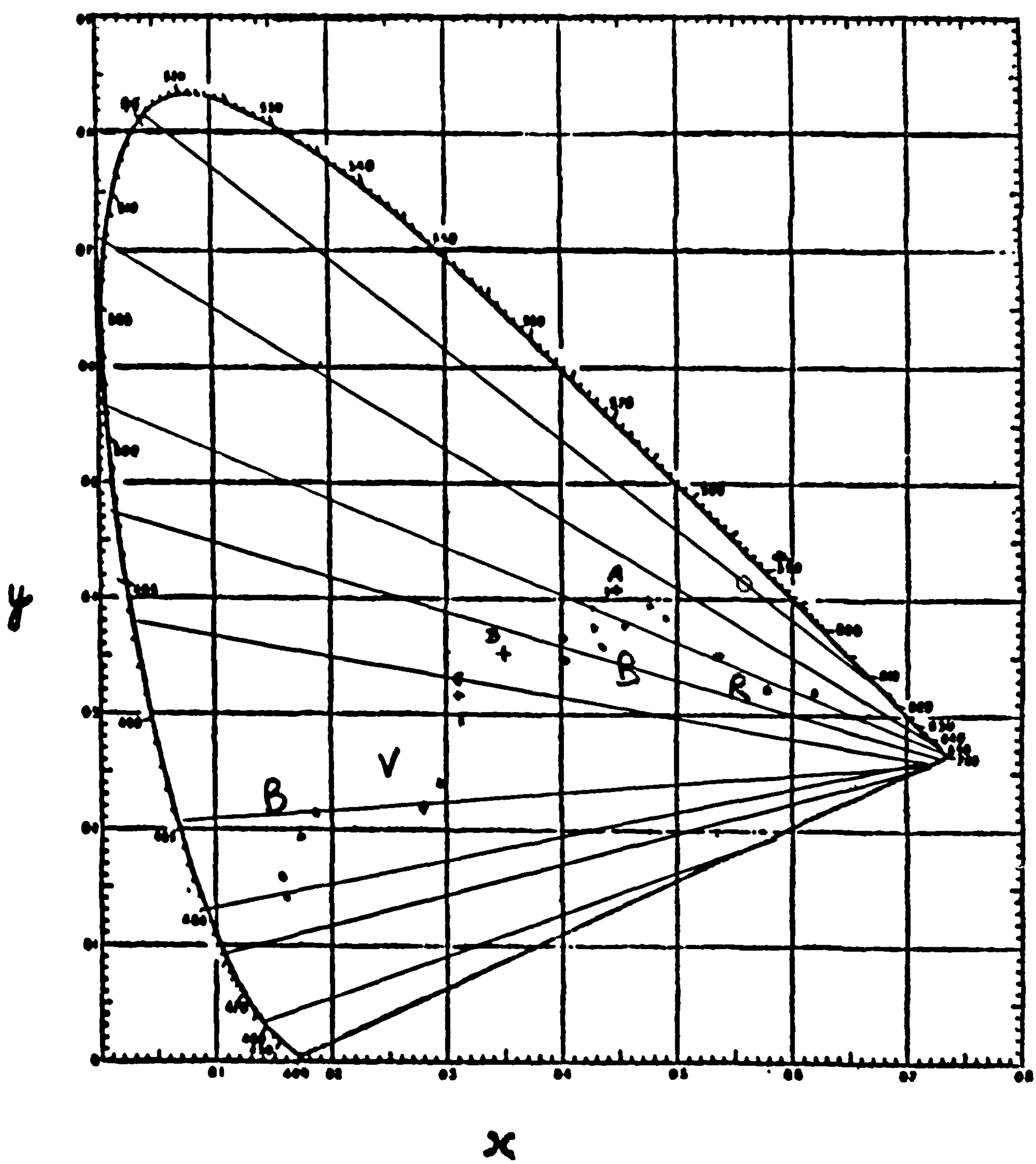
C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 1 Chromaticity plots of resistor bands and background colours of colour coded resistors used in trial with deuteranopic confusion loci.

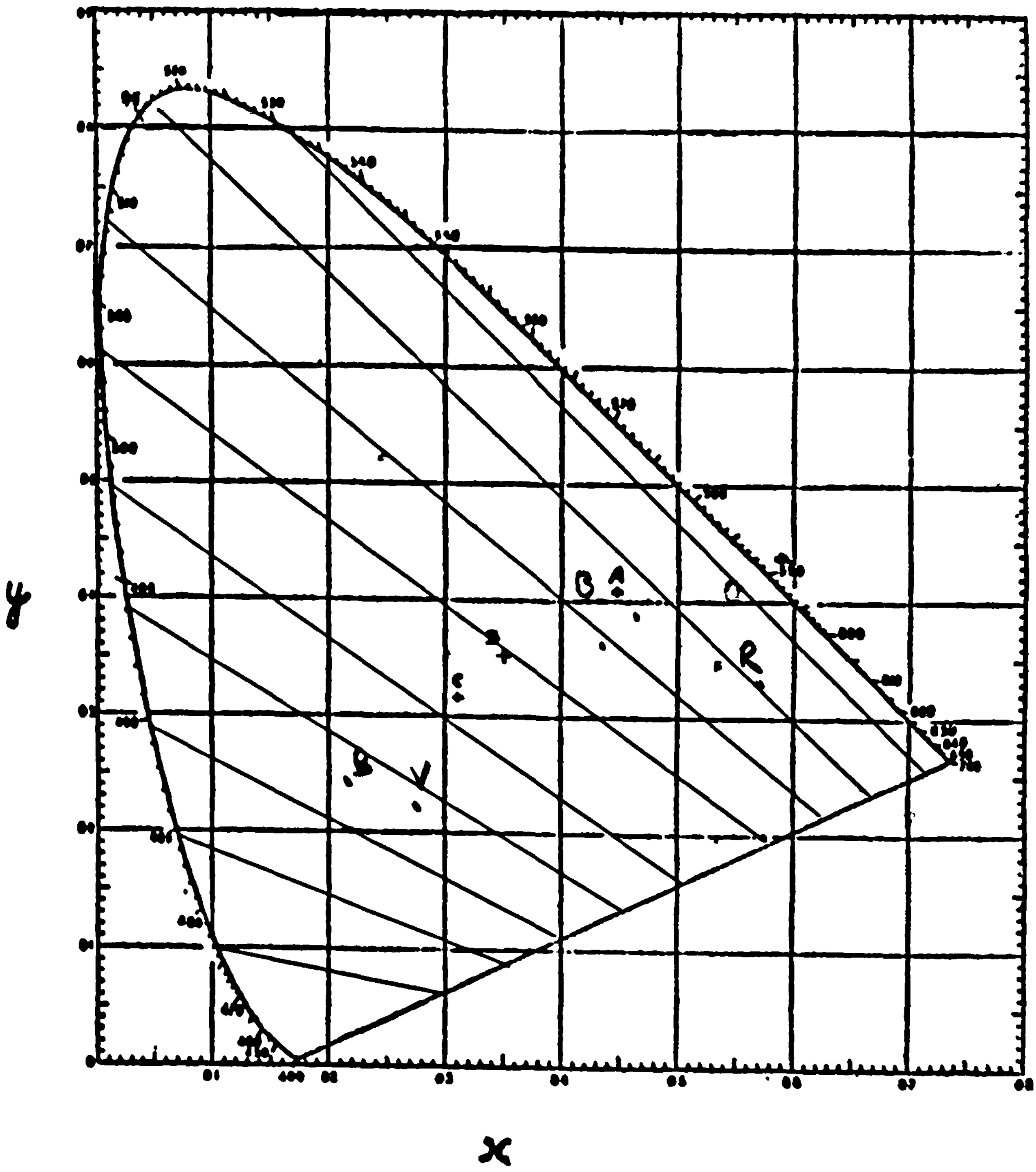
C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 14 Chromaticity plots of resistor bands and background colours of colour coded resistors used in trial with protanopic confusion loci.

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 15 Chromaticity plots of capacitor used in trial with deuteranopic confusion loci.

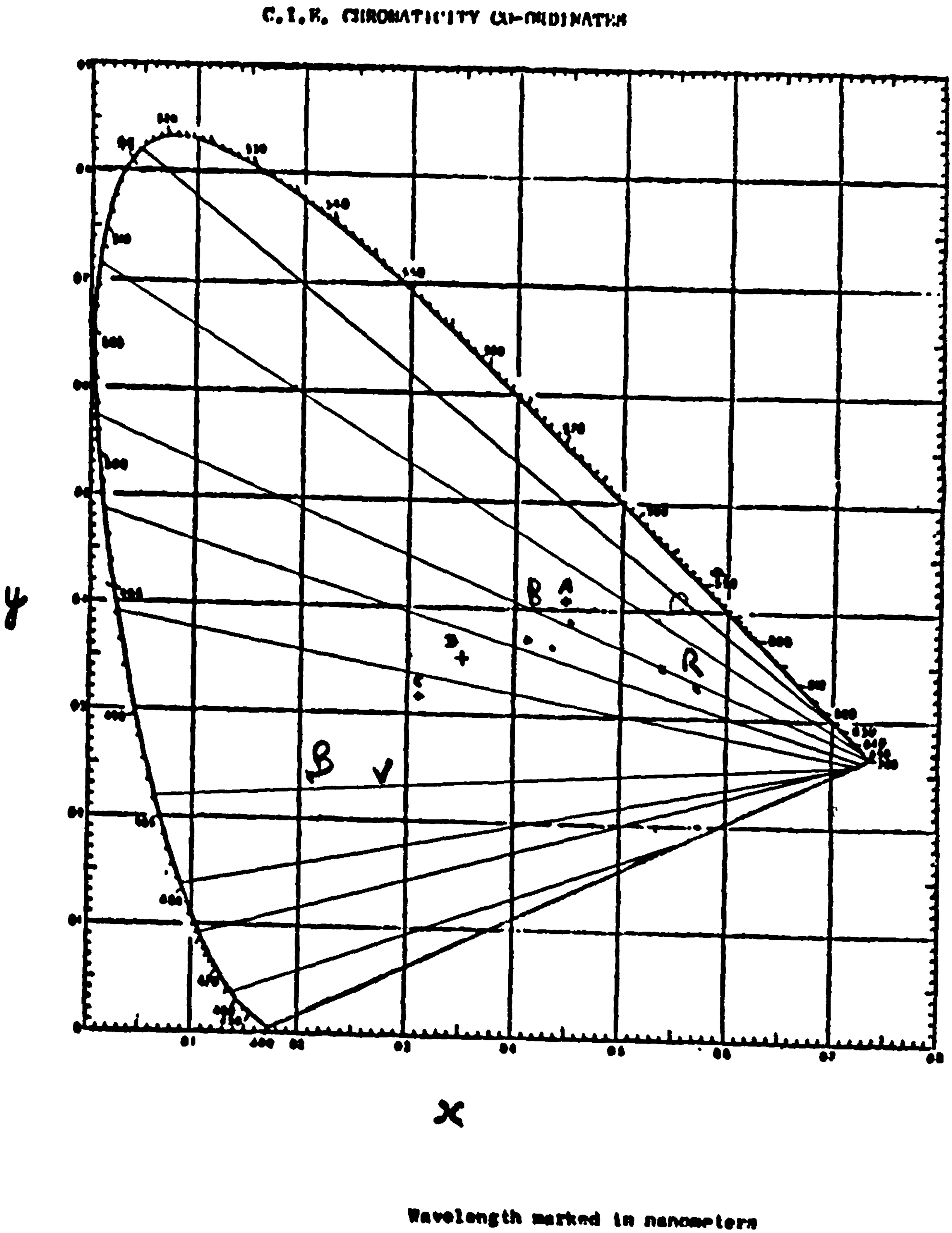
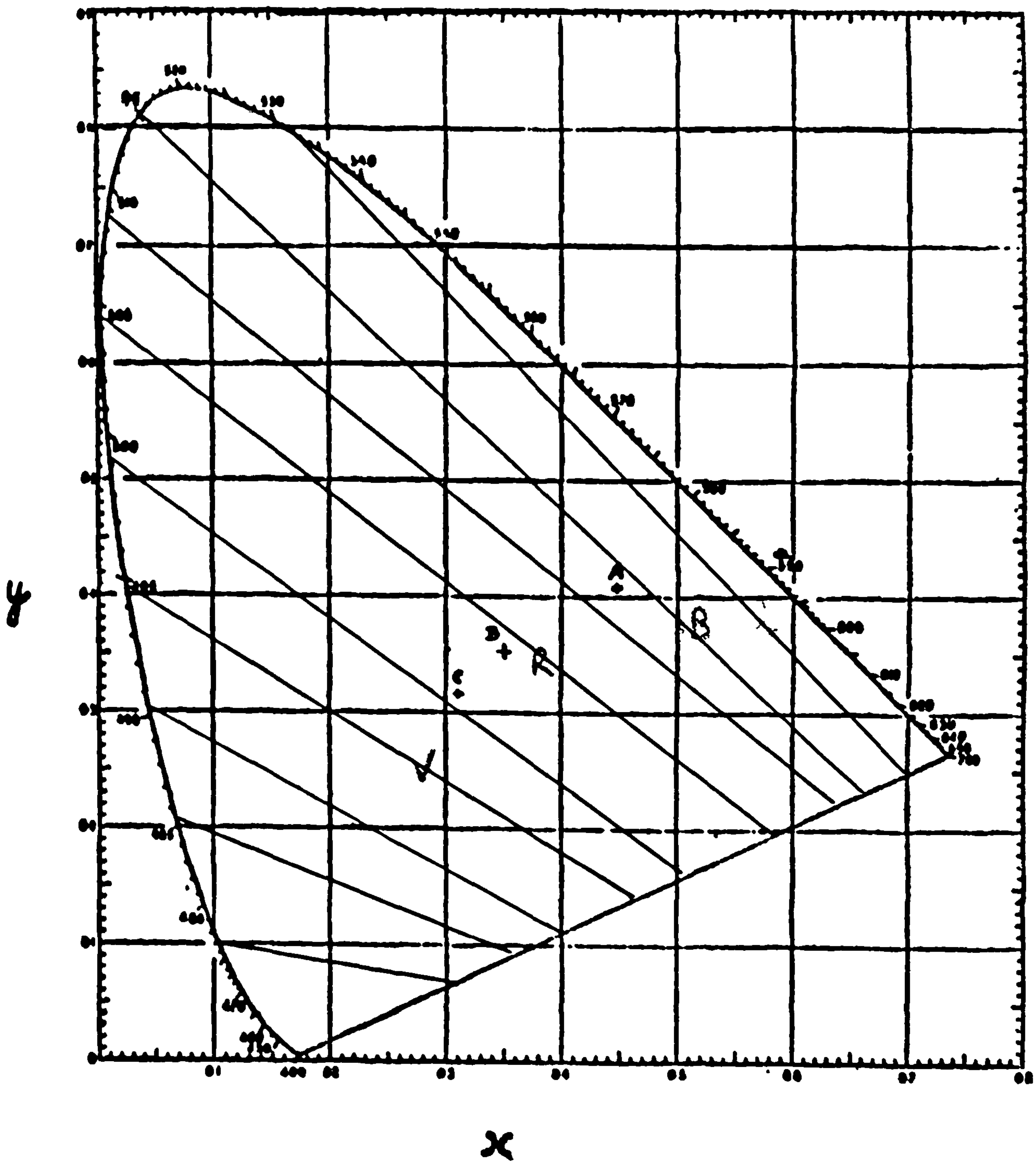


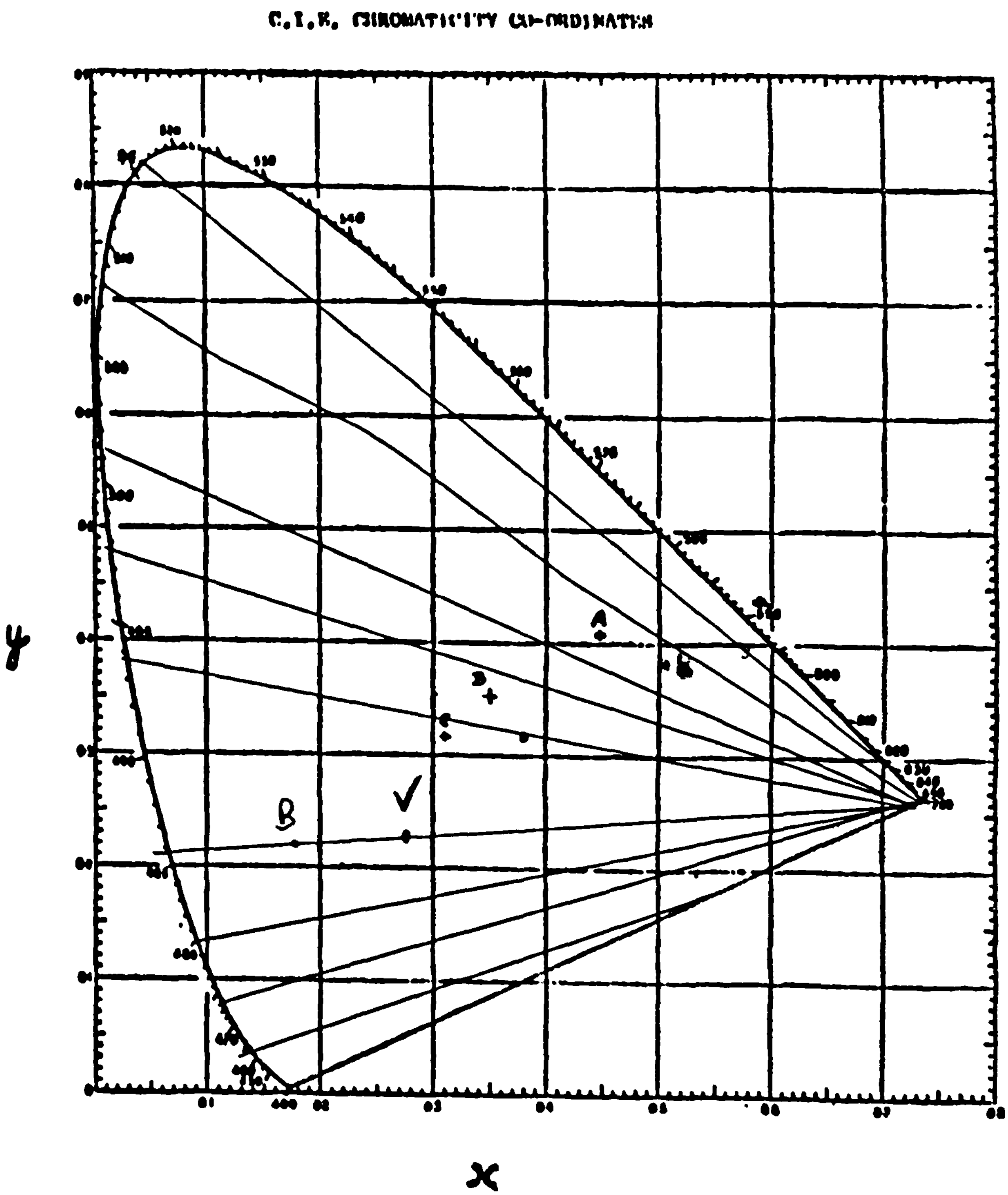
Figure 16 Chromaticity plots of capacitors used in trial with protanopic confusion loci.

C.I.E. CHROMATICITY CO-ORDINATES



Wavelength marked in nanometers

Figure 17 Chromaticity plots of wires used in trial with deuteranopic confusion loci.



Wavelength marked in nanometers

Figure 18 Chromaticity plots of wires used in trial with protanopic confusion loci.

Resistor No. and Colour	Munsell H/V/chr. Best match/s		C.I.E. values		
			Y	x	y
<u>Brown</u>					
No 1,2,3,5,8	7.5YR	2/4	0.03126	0.4690	0.3964
Background					
	7.5YR	2/2	0.03126	0.3889	0.3590
No 7 Background	5YR	2/2	0.03126	0.3880	0.3476
No 2,3 stripes	10YR	4/4	0.1200	0.4189	0.3948
<u>Red</u>					
No 1,4,5	7.5R	3/12	0.06555	0.6158	0.3129
	5R	3/12	0.06555	0.5884	0.2904
<u>Orange</u>					
No 1,2,3,4,5,	2.5YR	6/16	0.3005	0.5698	0.3990
7,8	2.5YR	6/14*	0.3005	0.5488	0.3947
<u>Green</u>					
No 3	5G	3/6	0.06555	0.2471	0.4100
	5G	3/8	0.06555	0.2228	0.4380
	2.5G	3/6	0.06555	0.2642	0.4342
	2.5G	3/8*	0.06555	0.2435	0.4752
<u>Blue</u>					
No 1,2	2.5PB	5/12*	0.1977	0.1793	0.1894
	2.5PB	4/10*	0.1200	0.1805	0.1888
	2.5PB	5/10*	0.1977	0.1968	0.2078
	5P	5/12*	0.1977	0.2806	0.1977
<u>Violet</u>					
No 8	5P	6/6	0.3005	0.2950	0.2585
	5P	6/4*	0.3005	0.3001	0.2778
	7.5P	5/4*	0.1977	0.3100	0.2750
	7.5P	6/4*	0.3005	0.3107	0.2831
<u>Yellow</u>					
No 8	7.5Y	7/10	0.4306	0.4400	0.4830
	7.5Y	8/10	0.5910	0.4283	0.4712

* indicates close approximation only

<u>Table 18 Colorimetric values of Resistors 1-8</u>

Matches were made by direct visual comparison with Munsell Book of colour (Gloss edition) under Illuminant C.
(All values refer to bands or stripes unless stated)

Resistor No. and Colour.	Munsell H/V/chr.		C.I.E. Values		
			Y	x	y
Brown					
No D.E Background	7.5YR	3/4	0.06555	0.4378	0.3865
No B,C,T Background	5YR	3/4	0.06555	0.4376	0.3715
No J,G Background	10YR	4/4	0.1200	0.4189	0.3948
No H Background	10YR	4/6	0.1200	0.4618	0.4213
No F,E,J,R,L	5YR	3/6	0.06555	0.4966	0.3908
No G	5YR	2/4	0.03126	0.4674	0.3738
No C,T	5YR	4/4	0.1200	0.4187	0.3679
No T	5YR	5/4*	0.1977	0.3968	0.3614
	7.5YR	4/4*	0.1200	0.4208	0.3809
	7.5YR	5/4*	0.1977	0.3991	0.3714
No H	10YR	3/4	0.06555	0.4341	0.4018
Red					
No P	10R	5/10	0.1977	0.5113	0.3630
No C,H,I	7.5R	3/12	0.06555	0.6158	0.3129
No O	7.5R	3/10	0.06555	0.5730	0.3240
No R	10R	4/10	0.1200	0.5418	0.3580
	10R	4/12	0.1200	0.5801	0.3588
Orange					
No Q,S,I,J,H	2.5YR	6/16	0.3005	0.5698	0.3990
Green					
No D	2.5G	5/8	0.1977	0.2710	0.4380
No N	2.5G	5/6	0.1977	0.2841	0.4045
No L	10GY	3/6	0.06555	0.2992	0.4717
	2.5G	3/8	0.06555	0.2435	0.4752
No F	5G	3/6	0.06555	0.2471	0.4100
	5G	3/8	0.06555	0.2228	0.4380
	2.5G	3/6	0.06555	0.2642	0.4342
No J	7.5GY	4/6*	0.1200	0.3355	0.4739
	10G	4/8	0.1200	0.2124	0.3799

* indicates close approximation only.

Table 19 Colorimetric Values of Resistors A-T

Matches made by direct visual comparison with Munsell Book of Colour (Gloss edition) under Illuminant C.
(All values refer to bands or stripes unless stated)

Resistor No. and Colour.	Munsell H/V/chr.		C.I.E, Values		
			Y	x	y
Blue					
No A	5PB	3/8	0.06555	0.1908	0.1799
No D	5PB	6/8	0.3005	0.2360	0.2365
	2.5PB	6/6	0.3005	0.2465	0.2599
No F	2.5PB	3/10	0.06555	0.1576	0.1600
	5PB	3/8	0.06555	0.1908	0.1799
	5PB	3/10	0.06555	0.1718	0.1562
No L	2.5PB	5/10	0.1977	0.1968	0.2078
No N	2.5PB	5/10	0.1977	0.1968	0.2078
	5PB	5/12	0.1977	0.1918	0.1858
No S	5PB	4/12	0.1200	0.1773	0.1659
Violet					
No B	10PB	5/6*	0.1977	0.2686	0.2412
No I	2.5P	4/8*	0.1200	0.2685	0.2089
	5P	4/6*	0.1200	0.2855	0.2150
No M	2.5P	4/6*	0.1200	0.2763	0.2300
	2.5P	4/8*	0.1200	0.2685	0.2089
	5P	5/8*	0.1977	0.2885	0.2296
Yellow					
No B	2.5Y	8/12	0.5910	0.4678	0.4589
No K	5Y	8/10*	0.5910	0.4376	0.4601
No M	5Y	8/12*	0.5910	0.4562	0.4788
	5Y	8/14*	0.5910	0.4699	0.4920
No O	5Y	8.5/8			
	5Y	8/8	0.5910	0.4158	0.4378
No Q	5Y	7/10*	0.4306	0.4509	0.4696
	5Y	7/12*	0.4306	0.4677	0.4857

*** indicates close approximation only.**

Table 19 Resistors A - T (continued)

Colorimetric values of capacitors used in trial

Matches were made by direct visual comparison with the Munsell Book of Colour (Gloss Edition) under Illuminant C.

All capacitors used were from one manufacturer only and this reduced the major colour differences which might have been expected had ones from different manufacturers been used. Nevertheless large differences in the browns were noticed in the sample used.

Capacitor No. and Colour	Munsell H/V/chr. Best match/s		C.I.E. Values		
			Y	x	y
Red					
No 1,2	7.5R	4/10	0.1200	0.5235	0.3351
	7.5R	4/12	0.1200	0.5603	0.3321
No 6,22	7.5R	5/12	0.1977	0.5280	0.3389
Yellow					
No 8,10,6,7	5Y	8/12	0.5910	0.4562	0.4788
	5Y	8/14	0.5910	0.4699	0.4920
Orange	2.5YR	6/14	0.3005	0.5488	0.3947
	2.5YR	6/12	0.3005	0.5215	0.3887
Brown					
No 26	7.5YR	4/4	0.1200	0.4208	0.3809
	5YR	4/4*	0.1200	0.4187	0.3679
No 23	7.5YR	5/4	0.1977	0.3991	0.3714
No 2	7.5YR	5/6*	0.1977	0.4440	0.3954
	5YR	5/6*	0.1977	0.4420	0.3808
Green					
No 2	2.5G	4/10	0.1200	0.2355	0.5006
Violet	2.5P	5/8	0.1977	0.2728	0.2240
Blue	10B	5/8*	0.1977	0.2067	0.2344

* Indicates close approximation only.

Table 20 Colorimetric Values of Capacitors

Colorimetric values of wires used in trial

Matches were made by direct visual comparison with the Munsell Book of Colour (Gloss Edition) under Illuminant C.

All wires used were taken from one electrical sheath.

Wire Colour	Munsell H/V/chr. Best Match		C.I.E. values		
			Y	x	y
Red	5R	4/4	0.1200	0.3916	0.3223
Orange	2.5YR	6/16*	0.3005	0.5698	0.3990
	2.5YR	5/14*	0.1977	0.5731	0.3953
Yellow	5Y	7/10	0.4306	0.4509	0.4696
Green	2.5G	4/8*	0.1200	0.2561	0.4597
Blue	10B	4/8	0.1200	0.1893	0.2160
Brown	2.5YR	4/8	0.1200	0.5071	0.3777
Violet	2.5P	4/6	0.1200	0.2763	0.2300
Grey	10B	5/1			

* Indicates close approximation only.

Table 21 Colorimetric Values of Wires

Observations and Recommendations

A comparison between the colorimetric values for resistor and capacitor bands as set out in the British Standard recommendation (see Table 17 and figures 10 to 10 b), and the colorimetric values obtained for resistor and capacitor bands used in the trial (see Tables 18 to 20 , and figures 9 to 11) show important discrepancies.

The most obvious departures from the B.S. colours are greens, browns, reds and yellows,(resistors only), which are, in practice, considerably more de-saturated than the B.S. recommended colours. There is also a large spread in the blues and violets for resistors. The orange bands are the only ones which agree well with the B.S. values, and show the least variability between resistors.

It is evident from these measurements that few manufacturers are attempting to adhere closely to the recommended colour values; discussions with manufacturers confirm this view. Such a situation leads to wide variability in band colour and the attendant difficulties in identification for both colour normals and colour defective observers. It is the opinion of the present writer that efforts will not be taken by manufacturers to standardise the colours used until this significant departure fro m the British Standard recommended colours is made known to them and tolerance values are specified, thus creating a greater incentive to conform.

Comparison of colours with confusion loci of Dichromats

A realistic assessment of the difficulties which would be expected by colour defectives can be obtained by superimposing the confusion loci of protanopes and deuteranopes on the colours of resistor and capacitor bands using the C.I.E. chromaticity diagram. This has been done for the B.S. colours (see figures 10, a,b) and the resistor and capacitor colours found in practice (see figures 13-16).

The choice of convergence points used in these calculations was made after a brief study of the literature. There appears to be good agreement between the authors on the location of the protanopic and tritanopic convergence loci and the accepted values are:

$x_p = 0.75 \qquad y_p = 0.25$

$x_t = 0.175 \qquad y_t = 0.006$

The exact location of the deuteranopic convergence point is not so clear because of the divergence of results obtained by the various investigators. NIMEROFF (1969) gives a concise comparison of the results obtained to date, showing a range in the x value from 1.30 to 2.30. He recommends that a weighted average of the experimentally obtained co-ordinates should be used, and suggests the values:

$x_D = 1.53 \qquad y_D = 0.53$

This weighted mean has been used in the calculationsmade in this study.

It is clear that many colours in all groups lay directly along confusion loci for dichromats. Tables showing the correlation between the chromaticity values of the resistor bands and the confusion loci are also presented (see Tables 22 to 27). A discussion on the association between these theoretical, expected confusions and the colour confusions made in practice during the trial, follow the practical results given below.

B.S. Band	C.I.E. co-ordinates of band colours x	y	Coeff Correlation	Gradient	Intercept
Yellow/ Orange	0.488 0.556	0.480 0.401	0.999	-0.964	0.944
Orange/ Red	0.556 0.626	0.401 0.314	0.999	-0.946	0.917
Green/ Brown	0.314 0.473	0.519 0.376	0.999	-0.860	0.786
Red/ Yellow	0.626 0.488	0.314 0.480	0.999	-0.956	0.931
Brown/ Red	0.473 0.626	0.376 0.314	0.997	-o.884	0.828
Yellow/ Brown	0.488 0.473	0.480 0.376	0.994	-0.9116	0.866
Green/ Red	0.314 0.626	0.519 0.314	0.997	-0.879	0.824
Blue/ Violet	0.184 0.289	0.156 0.205	0.990	-0.544	0.307

Table 22 B.S. Colours - Possible Deutan Confusions

Using weighted convergence points for deuteranopes, x = 1.53, y =-0.53

B.S. Band	C.I.E. co-ordinates of band colours x	y	Coeff. Correlation	Gradient	Intercept
Red/ Brown	0.626 0.473	0.314 0.376	0.998	0.453	0.593
Red/ Green	0.626 0.314	0.314 0.519	0.998	0.625	0.713
Yellow/ Orange	0.488 0.556	0.480 0.401	0.996	0.856	0.888
Green/ Brown	0.314 0.473	0.519 0.376	0.982	0.599	0.688
Yellow/ Red	0.488 0.626	0.480 0.314	0.976	0.884	0.897
Orange/ Red	0.556 0.626	0.401 0.314	0.970	0.748	0.803
Blue/ Violet	0.184 0.289	0.156 0.205	0.932	0.145	0.144
Grey/ Red	0.292 0.626	0.304 0.314	0.599	0.087	0.338

Table 23 B.S. Colours - Possible Protan Confusions

Using convergence points for protanopes, $x = 0.75$, $y = 0.25$

Band Colour	C.I.E. co-ordinates of band colours x	y	Coeff. Correlation	Gradient	Intercept
Yellow/ Orange	0.434 0.569	0.475 0.399	0.999	0.936	0.905
Orange/ Red	0.569 0.616	0.399 0.313	0.999	0.947	0.918
Yellow/ Brown$_1$	0.434 0.469	0.475 0.396	0.999	0.897	0.841
Yellow/ Brown$_2$	0.434 0.419	0.475 0.395	0.996	0.874	0.807
Brown/ Red	0.616	0.313	0.998	0.89	0.836
Red/ Yellow	0.616 0.434	0.313 0.475	0.998	-0.919	0.876
Green/ Brown	0.247 0.419	0.430 0.395	0.992	-0.788	0.689
Green/ Red	0.247 0.616	0.430 0.313	0.985	0.781	0.694
Blue/ Violet	0.180 0.295	0.189 0.259	0.988	0.576	0.357

Table 24 Resistors used in trial - Possible Deutan Confusions

Using weighted convergence points for deuteranopes, x = 1.53, y = -0.53

Band Colour	C.I.E. co-ordinates of band colours x	y	Coeff. Correlation	Gradient	Intercept
Red/ $Brown_2$	0.616 0.419	0.313 0.395	0.999	0.436	0.578
Red/ $Brown_1$	0.616 0.469	0.313 0.396	0.998	0.522	0.638
Green/ Red	0.247 0.616	0.430 0.313	0.996	0.349	0.519
Orange/ Yellow	0.569 0.434	0.399 0.475	0.995	0.719	0.795
Red/ Yellow	0.616 0.434	0.313 0.475	0.987	0.723	0.780
Green/ Brown	0.247 0.469	0.430 0.396	0.961	0.365	0.537
Red/ Orange	0.616 0.570	0.313 0.399	0.934	0.746	0.802
Blue/ Violet	0.181 0.295	0.189 0.259	0.567	0.072	0.203

Table 25 Resistors used in trial - Possible Protan Confusions

Using convergence points for protanopes, $x = 0.75$, $y = 0.25$

B.S. Band Colours	C.I.E. co-ordinates of band colours x	y	Coeff. Correlation	Gradient	Intercept
Violet/ Yellow	0.289 0.488	0.205 0.480	0.998	1.499	-0.245
Blue/ Green	0.184 0.314	0.156 0.519	0.974	3.3	-0.514
Green/ Grey	0.314 0.292	0.519 0.304	0.960	3.3	-0.586

Table 26 B.S. Colours - Possible Tritan Confusions

Using convergence points for tritans, x = 0.175, y = 0.006

B.S. Band Colours	C.I.E. co-ordinates of band colours x	y	Coeff. Correlation	Gradient	Intercept
Yellow/ Violet	0.434 0.295	0.475 0.259	0.996	1.803	-0.298
Brown/ Yellow	0.469 0.434	0.396 0.475	0.965	1.508	-0.249
Green/ Violet	0.247 0.295	0.430 0.259	0.681	2.405	-0.343

Table 27 Resistors used in trial - Possible Tritan Confusions

Using convergence points for Tritans, x = 0.175, y = 0.006

Results of Resistor and Capacitor Trials

The results presented in Tables 30 to 31 show the extreme difficulty that colour defective observers have in identifying correctly the colour code of electronic components.

Resistors

Dichromats are particularly at risk. Incorrect identification of the colour code of resistors could occur in twenty percent of cases for dichromats, (the proportion of incorrectly named bands in this study was 19.7% for deuteranopes and 19.3% for protanopes). Using these figures as a guide, at least one misidentification in band colour and hence resultant value of the resistor could be expected for every two resistors (total eight bands).

Anomalous trichromats perform considerably better. In this trial DA's made a total of 6.8% errors and PA's 8.5%. Thus one mistake in the identification of twelve resistors could be expected or predicted from these figures.

Tables 30a to 30b show the types of colour confusions made by the different groups of colour defectives, in particular the colour names given to the resistor bands. All groups of colour defectives had little trouble with the white, black, silver and gold bands.

TABLE 30a
RESISTORS; ERRORS IN COLOUR NAMING

Deuteranopes (16 Observers)

Colours as presented (rows) ↑ / Colours as named (columns) →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver	Gold
White	100											
Black		100										
Grey			63	2	6			8	5	14		
Brown		1		48	13	1		35	1			
Red		1		27	53			9	2			
Orange				1	3	82	11	2				
Yellow							100					
Green			4	22	7		2	62				
Blue									100			
Violet			8					1	51	40		
Silver											100	
Gold												100

Protanopes (11 Observers)

Colours as presented (rows) ↑ / Colours as named (columns) →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver	Gold
White	100											
Black		98		1	1							
Grey	2	2	80	2	5			5			2	
Brown		1		58	21	2		14			1	
Red		8		32	32		1	5				
Orange					2	88		10				
Yellow				1			98	1				
Green				21	11	11	3	47				
Blue					2			2	85	10		
Violet									52	47		
Silver											99	1
Gold												100

Percentages given are to the nearest percent

Colours completely missed by Deuteranopes

Brown not seen on Brown back	3%
Red not seen on Red	4%
Red not seen on Brown	3%
Green not seen on Brown	3%
Grey not seen on Brown	3%
Orange not seen on Light Brown	2%

Percentages given are to the nearest percent

Colours completely missed by Protanopes

Red not seen on Brown	19%
Red not seen on Red	3%
Green not seen on Brown	8%
Orange not seen on Light Brown	1%
Grey not seen on Green	2%
Brown not seen on Brown	2%
Violet not seen on Brown	2%

TABLE 30b

RESISTORS: ERRORS IN COLOUR NAMING

DEUTERANOMALOUS (22 Observers)

Colours as presented ↑ / Colours as named →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver	Gold
White	100											
Black		100										
Grey			85	2				2		11		
Brown			1	79	5			15				
Red				4	91	2		1				
Orange					3	96	1					
Yellow							99	1				
Green				4	2			94				
Blue									94	6		
Violet			4					2	15	79		
Silver											99	1
Gold												100

Percentages given to nearest percent.

Colours completely missed by Deuteranomalous Trichromats.

Brown not seen on Brown	1%
Grey not seen on Light Brown	1%
Grey not seen on Brown	1%
Red not seen on Red	1%
Red not seen on Brown	2%
Green not seen on Brown	1%

PROTANOMALOUS (6 Observers)

Colours as presented ↑ / Colours as named →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver	Gold
White	100											
Black		100										
Grey			88							12		
Brown		3	4	73	17							1
Red		4		15	71	4						
Orange						100						
Yellow	2						98					
Green				8		3		89				
Blue									100			
Violet			6						22	72		
Silver											100	
Gold											1	98

Percentages given to nearest percent.

Colours completely missed by Protanomalous Trichromats.

Brown not seen on Brown	1%
Red not seen on Brown	4%
Red not seen on Red	2%
Orange not seen on Brown	2%

Deutans

Deutans rarely misnamed the yellow and blue bands, but violet and brown gave the greatest difficulty. Only on forty-eight percent of occasions did the deuteranopes name brown correctly; the most frequent confusion was with green (thirty-five percent of occasions). A confusion of brown for green was also common for the deuteranomalous observers. Blue was a common misnaming for violet among the deuteranopes; on fiftyone percent of occasions violet was called blue and only forty percent of times was violet named as violet. Similar confusions were made by the deuteranomalous group. Red was correctly identified by deuteranopes only fifty-three percent of times; on most other occasions (twenty-seven percent of times) it was called brown. Considerably less difficulty with red was shown by the deuteranomalous observers. Grey was frequently misnamed by deutans though on more occasions for the deuteranopes (twenty-seven percent of times) than for the DA's (seventeen percent of times). Violet was the most frequent name incorrectly given to the grey bands by all deutans. Orange was occasionally confused with red and yellow by both groups.

Complete failure to identify the presence of a band was more frequent for the deuteranopes than the DA's, as the figures in the Tables indicate.

Protans

The identification of yellow gave the least trouble to both protanopes and PA's and for both groups of defectives red gave the greatest problems. For the protanopes red was correctly named on only thirty-two percent of occasions; it was called brown just as often. Protanomalous observers correctly identified red on seventy-one percent of presentations and brown accounted for another fifteen percent. Green and violet were both confused on forty-seven percent of occasions; green was often called brown by protanopes and violet was frequently called blue. Similar patterns emerge for the P.A. . group though they are less marked; violet was called blue on twenty-two percent of presentations. Orange was occasionally named as green by the protanopes, but was always correctly identified by the P.A.'s.

Far more coloured bands were completely missed by the protanopes than any other group. A red band on a brown background gave most difficulty; this was missed on nineteen percent of occasions. Failure to see green bands on brown resistors was also common.

Tritanope

A congenital tritanope aged twenty-five years performed the resistor task. He made only three errors - violet he called brown twice and green he called white once.

Colour Normals

Few mistakes were made by the thirteen colour normals who took part in the trial. All observers were under twenty-five years except one who was in his forties.

Nine observers made no errors at all. One observer made two errors, one made three errors, one made four errors and another made seven errors. The observer who made seven errors repeated the trial and subsequently made no errors.

There was some dispute between normal observers over the colour of the third band of resistor P. The band could be interpreted as orange or red by normal observers since the colour was neither a clear orange or a definite red; both responses were accepted as correct. This example shows the great difficulty that even colour normals have in correctly interpreting the colour code when the colours used do not conform to the British Standard recommendations.

It appeared that motivation played a major part in deciding whether the bands were identified correctly and carelessness could have accounted for the seven errors made by the one observer who subsequently repeated the task and made no mistakes at all.

Of the errors that were made by the colour normals, grey, brown and red gave most trouble. In each of these groups correct identification occurred on twenty-six percent of occasions. Grey was mistaken for blue on four percent of times, red was called orange three percent of times and failure to see a brown band on a brown background occurred for two percent of presentations. Excluding the careless observers first attempt there were a total of nine errors for thirteen observers.

It might be reasonable to expect colour normal observers to make one or two errors in the identification of one hundred and eight colours of such small dimensions, as a result of fatigue, carelessness or boredom. WALRAVEN AND LEEBECK (1958) found that normal observers made up to ten errors when identifying two hundred and seven bands under levels of illumination equivalent to that used in this study.

Effect of repeating resistor trial by colour defectives

Certain selected colour defective observers repeated the resistor trial to see if familarity with the task made any difference to performance. A comparison of the errors made for the first and second attempt is given below in Table 33.

TABLE 28
PROPORTION OF RESISTOR BANDS INCORRECTLY NAMED OUT OF TOTAL

RESISTORS

Proportion incorrectly named %.	
Deuteranomalous (DA)	6.8
Deuteranopes (D)	19.7
Protanomalous (PA)	8.5
Protanopes (P)	19.3
Deutans (D+DA)	13.2
Protans (P+PA)	13.9
Anomalous Trich. (DA+PA)	7.7
Dichromats (D+P)	19.5

TABLE 29
PROPORTION OF CAPACITOR BANDS INCORRECTLY NAMED OUT OF TOTAL

CAPACITORS

Proportion incorrectly named %.	
Deuteranomalous (DA)	2.5
Deuteranopes (D)	19.2
Protanomalous	*
Protanopes (P)	16.0

* Insufficient number of observers.

Observer No.	Colour Defect	Resistor Errors	
		First attempt	Second attempt
D27	D	29	28
P 6	P	22	15
P 5	P	11	7
P21	PA	2	6
D55	DA	0	0
D48	DA	2	0
D61	DA	10	10

Table 32 Resistor trial error scores for colour defective observers who repeated the trial Out of 108

There appears to be little change in the number of errors made for attempts one and two. A comparison between the types of errors made at the first attempt and second attempt is given in Table. 33.

Observer P6 was an electrical engineer who was familiar with the resistor code and was able to compensate for his colour vision defect to some extent by a knowledge of the preferred colours used for the code. He had difficulty in seeing the violet bands, but knew that they usually occurred.between the two yellow bands, which he could easily identify. His first attempt was based on colour recognition alone, and in his second attempt a slight reduction in errors was achieved by a knowledge of the most frequent combination of colours used by manufacturers. The differences involved are shown in Table 33.

Observer	Errors First attempt		Errors Second attempt	
P 6	Red/Brown	5	Red/Brown	6
	Green/Brown	4	Green/Brown	4
	Violet/Blue	6	Violet/Blue	1
	Red/Black	1	Red/Black	2
			Green/Red	1
	Green not seen on Brown	3	Red not seen on Red	1
	Red not seen on Red	1		
	Red not seen on Brown	2		
D61	Grey/Green	1	Grey/Green	1
	Blue/Violet	3	Blue/Violet	1
	Brown/Green	5	Brown/Green	3
			Grey/Violet	1
			Red/Yellow	1
			Red/Brown	2
	Brown not seen on Brown		Brown not seen on Brown	

Table 33 . Comparison between errors made at first and second attempts by two colour defective observers.

FIGURE 19

ERRORS MADE AT ELECTRICAL TASK

RESISTORS

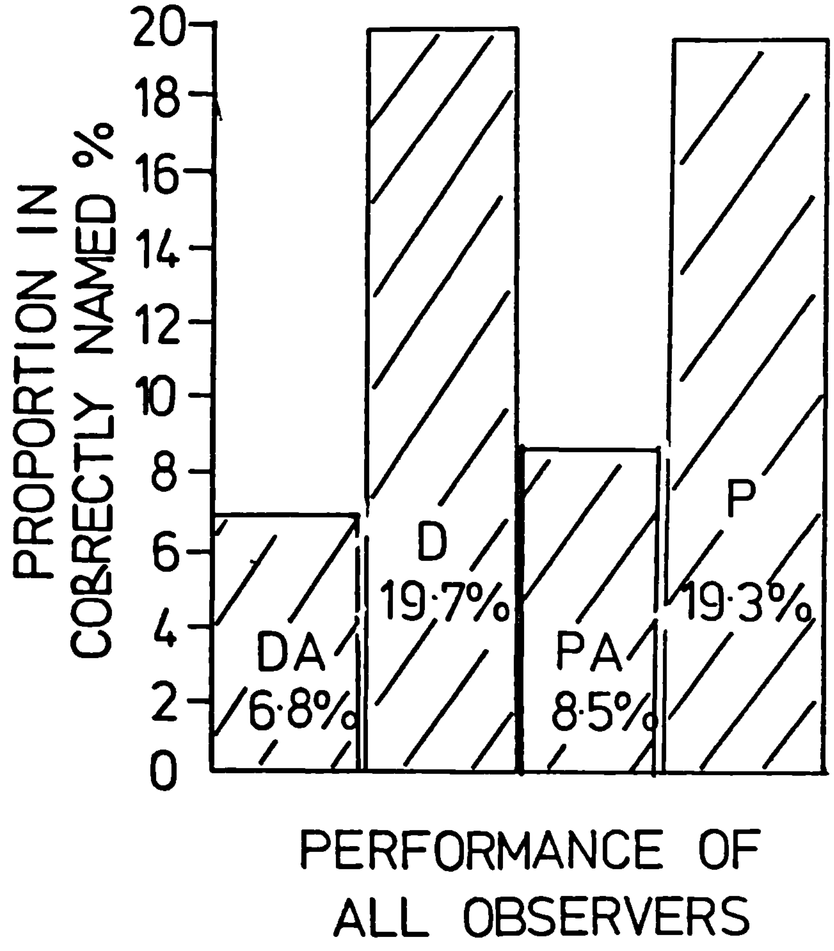
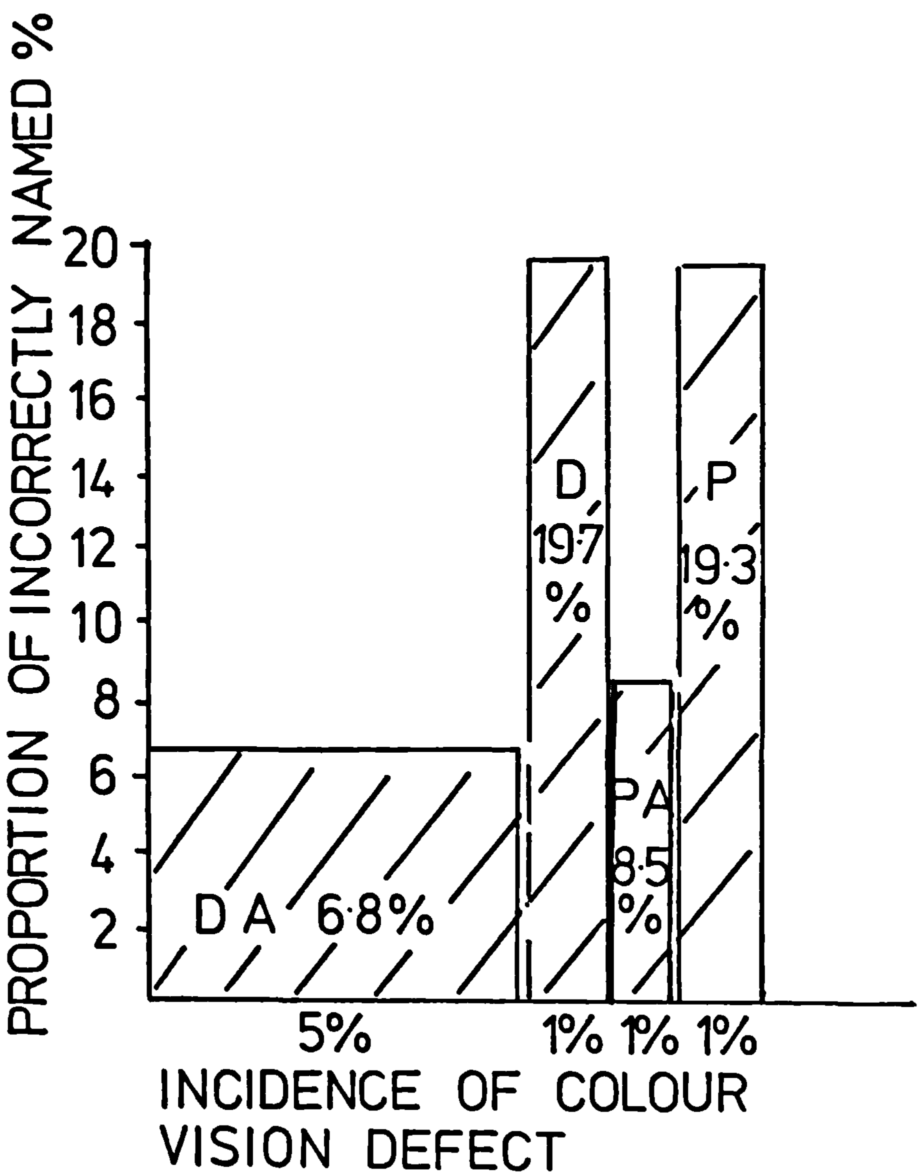


FIGURE 21

ERRORS MADE AT ELECTRICAL TRIAL: RESISTORS



RESULTS - CAPACITORS

A realistic assessment of the errors made in identifying the colour code of capacitors is only possible for protanopes, deuteranopes and DA's because insufficient unmbers of PA observers took part in the trial. As with the resistor naming white and black posed no problems at all. Silver and gold did not appear in the capacitors selected. Blue was correctly identified by observers in all groups on every occasion.

Deutans

By far themost frequent confusion for all deutans was the naming of violet as blue; violet was correctly named on only twenty-three percent of occasions by the deuteranopes - on seventy percent of occasions it was identified as blue. The DA's had less difficulty, but it was still the major confusion made by the group - on eighty-four percent of occasions violet was called violet, and on fourteen percent of presentations it was named blue. It is somewhat surprising that the reverse confusion never occurred; blue was always correctly identified by both groups. Grey was frequently misinterpreted by deuteranopes, but never by the DA's. Only on forty-seven percent ofoccasions was it correctly identified as grey - the other names given were violet, blue, green and white. Brown also gave difficulties to the deuteranopes, but only rarely to the DA's. The most frequent naming of brown by all deutans was "green". Red was often called brown or green by the deuteranopes and on a very few occasions it was mistakened by the DA's also. Orange gave little trouble to DA's and on the few occasions when it did orange bands were called red. Green, yellow, red and brown were the colour names allocated to orange by deuteranopes, on a total of eleven percent of occasions. Green caused no problems to the DA's, but was misidentified on ten percent of presentations by deuteranopes - usually it was called brown.

Comparing the confusions made by deutans at the resistor and capacitor tasks shows significant similarities. The most frequent confusions in descending order for the tasks are given in the Table below:

Deuteranopes	
Resistors	**Capacitors**
Violet	Violet
Brown)	Brown)
Red)	Grey)
Grey)	Red
Green)	
Deuteranomalous Trichromats	
Resistors	**Capacitors**
Violet)	Violet
Brown)	Brown
Grey	Red)
Red	Orange)

N.B. Colours grouped show similar percentages of errors.

Table 3 4 Colours most frequently misnamed by deutans in resistor and capacitor trials.

Slightly more errors were made for resistors than for capacitors, but this might be expected because the area of colour exposed is much smaller for resistors than for capacitors.

Protans

As with the deutans, the most frequent confusion was the naming of violet, blue. Violet was correctly named on only twenty-eight percent of occasions (compared with twenty-three percent for the deuteranopes). Brown also gave considerable trouble - it was identified correctly only on forty-eight percent of occasions; on forty-three percent of occasions it was mistakened for green. Grey and green were confused equally on twenty-two percent of presentations. As with the deuteranopes grey was frequently mistakened for white by the protanopes, but unlike the deuteranopes it was never called violet. Red caused trouble on thirty percent of occasions - it was called either green or brown. Failure to identify a capacitor band altogether occurred quite frequently where green and brown were placed next to each other indicating a lack of discrimination between the two.

As with the deutan groups a comparison between the errors made by protanopes at resistor and capacitor tasks shows marked similarities. The most frequent confusions in descending order for the tasks are given in the Table below:

Protanopes	
Resistors	**Capacitors**
Red	Violet
Green)	Brown
Violet)	Red
Brown	Green)
	Grey)

N.B. Colours grouped show similar percentages of errors.

Table 35 Colours most frequently misnamed by protanopes in resistor and capacitor trials.

Individual Observer variations

A considerable degree of observer variation occurred in the errors made at both resistor and capacitor tasks. These are given in Table 36 . Forty-five percent of DA's made no errors at the capacitor task. The deuteranopic observer who made the most errors with the resistors also made the greatest number of errors, out of all deuteranopes, for the capacitor task. Overall those protanopes who made many errors at the resistor task also made numerous errors when naming the bands of capacitors. The protanopic observer who made the lowest number of errors for the resistor naming task also made the lowest number of errors on the capacitor task.

The data presented in Table 36 indicates that dichromats made significantly more errors than anomalous trichromats for both resistor and capacitor tasks.

Colour Vision	Range of Errors Per Person Outside Limits			
	Resistors	σ	Capacitors	σ
Protanopes	12 - 34	7.0	5 - 34	9.4
Deuteranopes	14 - 39	9.8	5 - 31	9.4
Protanomalous	1 - 23	9.2	0 - 2	1
Deuteranomalous*	1 - 21	7.9	0 - 19	4.2

* excludes errors of 34 for resistors and 19 for capacitors made by an elderly DA who also showed acquired tritan defects.

Table 36 Range of Errors at Resistor and Capacitor tasks showing individual observer variations.

FIGURE 20

CAPACITORS

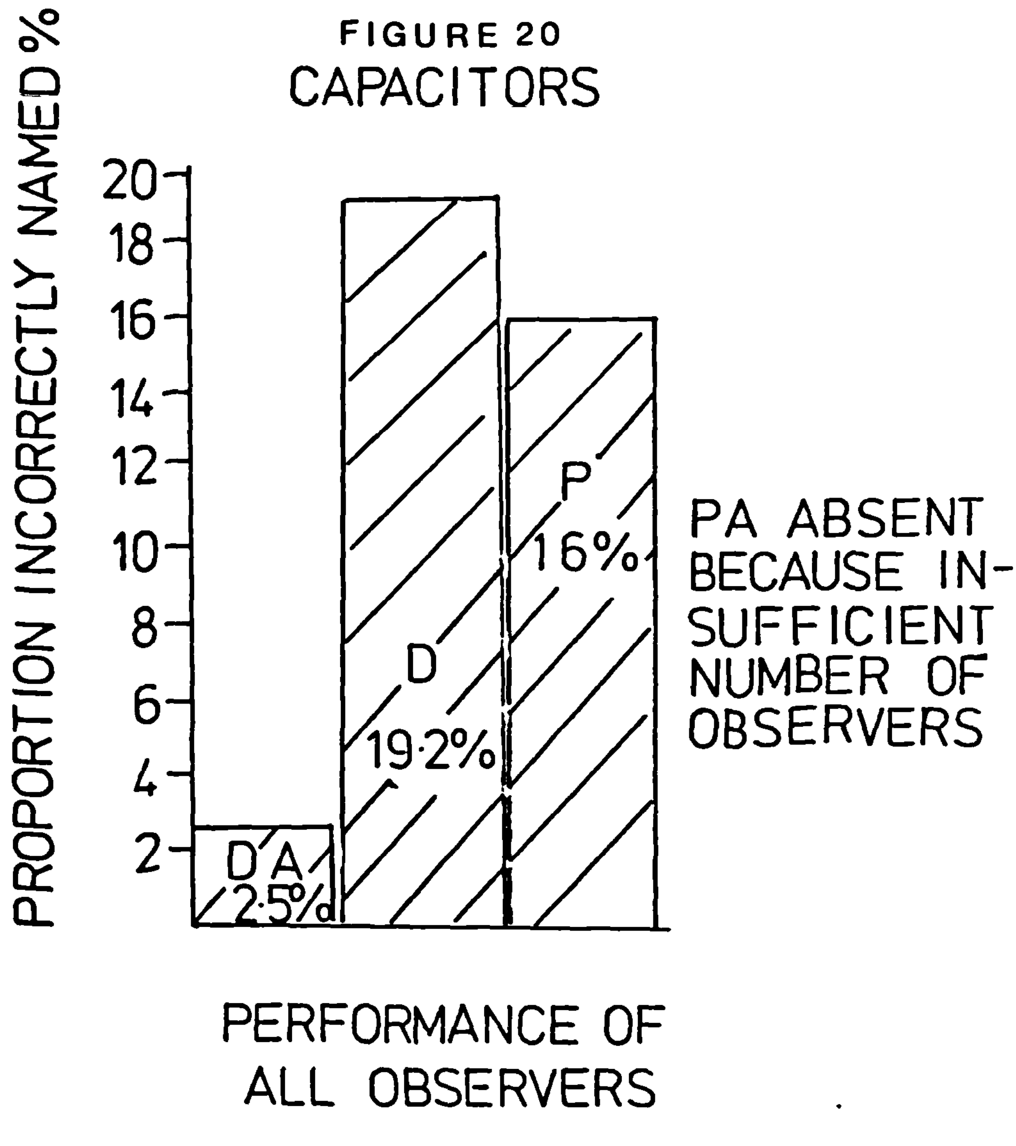


FIG 22
ERRORS AT CAPACITOR TRIAL

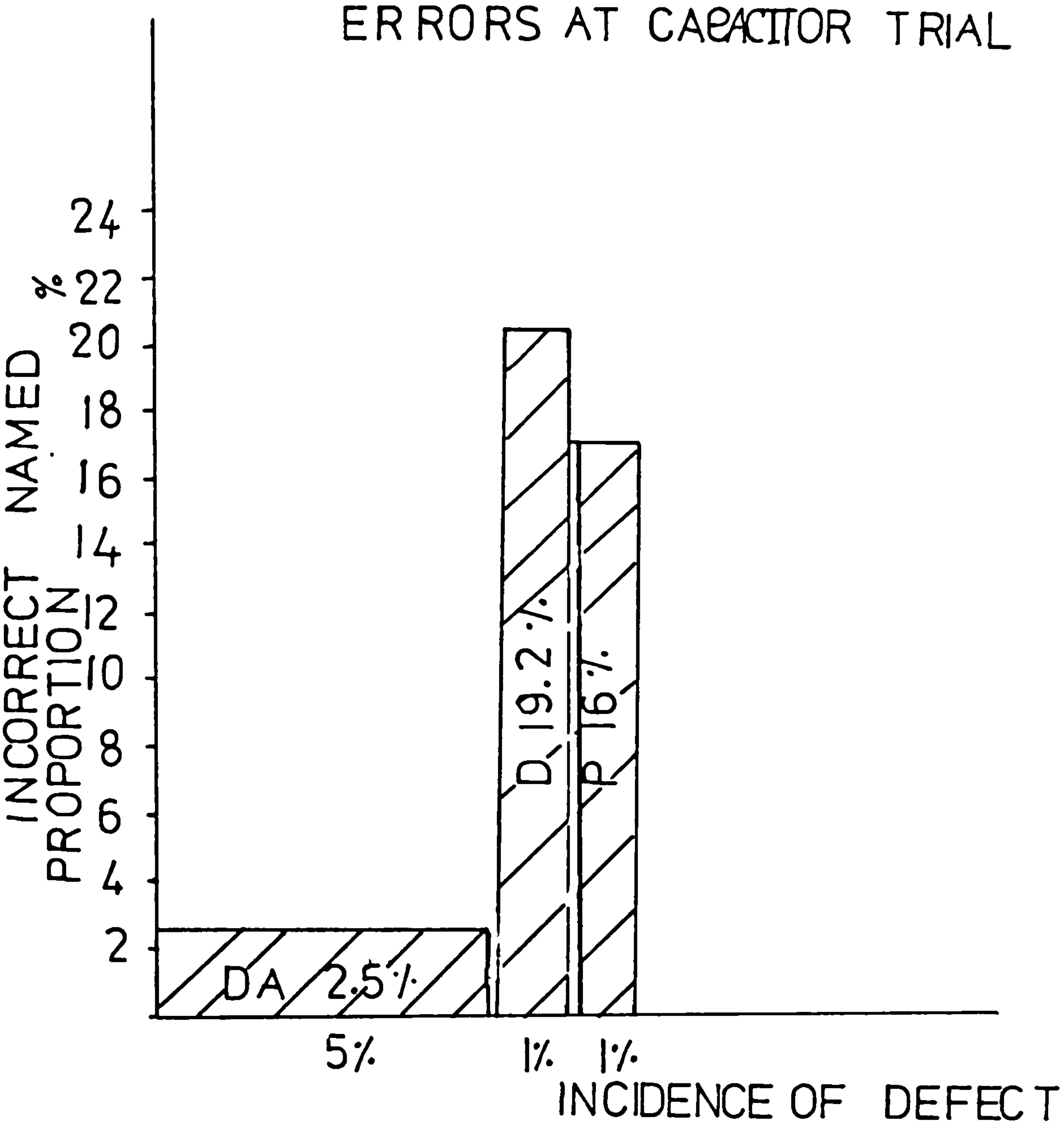


TABLE 31a
CAPACITORS: ERRORS IN COLOUR NAMING

Deuteranomalous (22 Observers)

Colours as presented ↓ / Colours as named →	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet
White	100									
Black		99			1					
Grey			100							
Brown				94	1			5		
Red				1	97	1		1		
Orange					3	97	1			
Yellow					1	1	99			
Green								100		
Blue									100	
Violet			2						14	84

Colours as named →

Percentages given to nearest percent

Colours completely missed by Deuteranomalous Trichromats

Red not seen 1%

TABLE 31b

CAPACITORS: ERRORS IN COLOUR NAMING

Deuteranopes (15 Observers)

Colours as presented ↑ / Colours as named →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet
White	100									
Black		100								
Grey	13		47					7	13	20
Brown				54	4	1		41		
Red				19	65	1		13		
Orange				1	2	89	3	5		
Yellow					1		99			
Green				5	1	3		90		
Blue									100	
Violet									77	23

Percentages given to nearest percent.

Colours completely missed by Deuteranopes

Red not seen 2%
Green not seen 1%

Protanopes (9 Observers)

Colours as presented ↑ / Colours as named →

	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver
White	100										
Black		100									
Grey	11		78								11
Brown				48	8			43			
Red				13	69			18			
Orange						100					
Yellow						3	97				
Green				3	6		5	78			
Blue									100		
Violet									72	28	

Percentages given to nearest percent.

Colours completely missed by Protanopes

Brown not seen 10%
Green not seen 8%

RESISTORS: ERRORS IN COLOUR NAMING

Colour Normals (13 Observers)

Colours as presented ↑ / Colours as named →	White	Black	Grey	Brown	Red	Orange	Yellow	Green	Blue	Violet	Silver	Gold
White	100											
Black		100										
Grey			96						4			
Brown				96				1				1
Red				1	96	3						
Orange						100						
Yellow							100					
Green				1				99				
Blue									100			
Violet									1	99		
Silver											100	
Gold			2									98

Colours as named →

Percentages given to nearest percent.

Colours missed by Normals.

Brown not seen on Brown 2%

Comparison of expected colour confusions and actual confusions made in the trial.

A comparison has been made of the coloured bands which were actually confused in the trial and the colour confusions which are expected, or can be predicted, on the basis of the positions on the C.I.E. chromaticity chart relative to the confusion loci for dichromats. Agreement occurred only between pairs of colours showing similar luminance values. It therefore appears that a large difference in the luminance value was a sufficient clue for the colour defective to be able to distinguish between the colours. The results arepresented in Table 37 and 38 . A luminance difference of up to seven percent was insufficient for the colour defective observer to be able to detect a difference between the bands; a luminance difference of seventeen percent and over was sufficient for a distinction to be made.

It can be concluded, therefore, that a difference in the luminance values between certain pairs of colours is a very beneficial aid to the colour defective and with out this clue he would be unable to tell them apart.

Expected confusions B.S. colours and colours in practice			Actual confusions made
Colours	Luminance value %	Luminance Difference%	
Red Brown	6.8 3.2	3.6	Yes
Red Green	6.8 10.3	3.5	Sometimes
Yellow Orange	50.9 24.4	23.5	No
Green Brown	10.3 3.2	7.1	Yes
Yellow Red	50.9 6.8	44.1	No
Orange Red	24.4 6.8	17.6	No

Table 37 Comparison of expected colour confusions and actual confusions made in trial - PROTANS

Expected confusions B.S. colours and colours in practice			Actual confusions made
Colours	Luminance value %	Luminance Difference%	
Yellow Orange	50.9 24.4	26.5	No
Orange Red	24.4 6.8	17.6	No
Green Brown	10.3 3.2	7.1	Yes
Red Yellow	6.8 50.9	44.1	No
Brown Red	3.2 6.8	3.6	Yes
Green Red	10.3 6.8	3.5	Sometimes
Yellow Brown	50.9 3.2	47.7	No
Blue Violet	9.4 6.4	3.0	Yes

Table 38 Comparison of expected colour confusions and actual confusions made in trial - DEUTANS

Wire Sorting Task

Eighty plastic covered coloured wires taken from a standard bundle of Post Office wires, each 15 cm long and imm in diameter, were used, most to form "double-twisted wires", using the combination adopted by the Post Office. Observers were asked to sort through the wires and make up pairs with similar double twisted wires.

Eight single wires were selected for a colour naming task. These wires had the same dimensions as the double twisted wires. Observers were asked to write down thecolour names for each one. No list of colour names was given.

Single Wires	Double-twisted wires	
Violet	Violet/green	Red/green
Blue	Green/white	Blue/black
Green	Blue/violet	Orange/black
Red	Yellow/orange	Red/orange
Pink	Red/brown	Brown/black
Yellow	Yellow/blue	Blue/red
Brown	Yellow/brown	Yellow/green
Orange	Violet/brown	Blue/white
	Green/orange	Grey/violet
	Red/grey	black/grey

Results

1. Single wires - colour naming task

Thirty-five observers took part (nine protanopes, twelve deuteranopes, five P.A's and eighteen D.A's). No errors were made by the anomalous trichromats; in every case the wires were correctly identified. Of the twelve deuteranopes, three made one error only, seven made two errors and two made three errors. Of the nine protanopes, two made one error, five made two errors and two made three errors. The errors in colour naming are shown below in Table 43 .

Colour Confusions	Deuteranopes	Protanopes
	Numbers refer to incidence of confusion.	
Violet called blue	2	7
Violet called grey	1	
Violet called green	1	
Violet called red	1	
Blue called brown	1	
Green called brown	1	
Green called pink	1	
Orange called red	1	
Orange called green	2	1
Red called brown	1	3
Pink called grey	2	6
Pink called brown	1	
Pink called green	4	
Brown called Red		1
Brown called green	3	

Table 43 Errors in colour naming - Single Wires

2. <u>Single and Double-twisted Wires - Pairing task</u>

The same number of observers as the single wire task took part. No errors were made by the P.A's, and fourteen out of the eighteen D.A's (seventy-eight percent) paired all wires correctly. More mistakes were made by dichromats than anomalous trichromats. The colour confusions made are given below in Tables 44 and 45 .

Single Wires - most common confusions in pairing		
Deuteranomalous	Deuteranopes	Protanopes
Blue/violet Blue/brown	Blue/violet Red/green Red/brown	Blue/violet Orange/green

Table 44 Common Errors made in Pairing Single Wires

Conclusions

Protanopes most frequently confuse green and orange colours when they appear in a double-twisted form with another colour. More varied confusions are made by deuteranopes who show confusions between green and brown, green and red, orange and brown, orange and green, red and brown, grey and green, yellow and orange. Photographs showing some of these confusions are given.

Deuteranomalous	Deuteranopes	Protanopes
(Red+Blue)+(Brown+Violet)	(Violet+green)+(violet+brown)	(Blue+red)+(violet+brown)
	(Orange+red)+(orange+green)	(Brown+black)+(green+red)
	(Yellow+brown)+(yellow+green)	(Yellow+green)+(yellow+orange)
	(Green+yellow)+(green+orange)	(Violet+yellow)+(violet+green)
	(Red+green)+(red+grey)	(Red+orange)+(red+green)
	(White+brown)+(White+green)	(White+green)+(white+orange)
	(White+green)+(white+orange)	(Violet+orange)+(violet+green)
	(Green+red)+(Green+brown)	
	(Red+brown) +(red+green)	
	(yellow+orange)+(yellow+green)	

Table 4 5 Confusions in Pairing Double-twisted Wires

Electrical Trial

Wire sorting task

Results of an elderly deuteranope

Recommendations for a new Resistor/Capacitor Code

Considerable thought was given to a code using colours which are not confused by red/green colour defectives. The task proved difficult because when all the likely confusion colours are omitted from the present code only black, orange, violet and brown remain. Suggestions have already been made in this study to use a universal white background for colour-coded resistors and capacitors lacquered to avoid soiling. The suggested code given below necessitates the use of double stripes to indicate one band value.

Black black	1
Black orange	2
Black violet	3
Black brown	4
Orange orange	5
Orange violet	6
Orange brown	7
Violet violet	8
Violet brown	9
Brown brown	10

It is appreciated, however, that the additional difficulty involved in using twice as many bands (eight instead of the present four) probably makes this system unacceptable to manufacturers.

DISCUSSION OF RESULTS

Errors made at the Electrical Trial and colour vision test score

The errors made by colour defective observers for the naming of colours of resistor and capacitor bands and the wire sorting task, together with the errors scored on standard colour vision tests, are given in Tables 39a to 39b. The data is presented in graphical form in figures 23 to 40. A comparison is useful because it indicates how far clinical colour vision tests are suitable for predicting practical abilities at industrial colour work.

It is clear that there is little correlation between the errors made at the practical tasks and the colour vision test scores. This is not altogether surprising because the two tasks are designed to test quite different abilities. Similar results were obtained very recently in an unpublished Australian study using colour coded cables and the 100 Hue Test and H.R.R. plates. (Personal communication Alexander 1976). Analysis of the data (the relationship between the errors at the practical task and the colour vision test scores) produced a low coefficient of correlation for all graphs, and the lines of best fit are indicated on the data. Table 40 show the coefficient of correlation for each set of data. Overall, (that is taking the three tasks together) the coefficient of correlation is highest for the F-M 100 Hue test, the Lovibond Colour Vision Analyser and the D.15 test. A very low correlation is obtained for the electrical tasks and the Ishihara test. It is well known that the Ishihara test is inadequate for a quantitative diagnosis of defective colour vision and is most useful as a screening test. Most colour defectives fail the majority of plates, obtaining a high error score for the test irrespective of theirtype or degree of anomaly. Performance at the practical tasks, in particular the resistor band identification, is more related to the degree of defect, since anamalous trichromats generally made fewer errors than dichromats. It was not, therefore, surprising to find that on plotting the practical task score errors against the Ishihara error score the data was grouped along the ordinate at the point of maximum Ishihara score on the abscissa. WALRAVEN AND LEEBECK (1958) obtained similar results. This analysis confirms the inadequacy of the Ishihara test to predict the practical ability of a colour defective observer at industrial colour work involving colour naming. On the basis of these results it is possible to recommend the use of the Lovibond Colour Vision Analyser, the D.15 test or the 100 Hue test for industrial situations where an estimate of practical ability is required. Those observers who were classified as dichromats by the Nagel anomaloscope (identified with boxes in the graphs) tended to have higher overall error scores on the 100 Hue test (in excess of 150) and performed correspondingly badly at the resistor and capacitor tasks. Similarly anomalous trichromats who made error scores of less than 150 on the F-M 100 Hue test also made few errors at the resistor, capacitor and wire-sorting tasks.

Another method of analysis related to the line of best fit was attempted. A summation of the deviations of the points on the y axis measured from the line of best fit was made for each set of data using only results obtained for observers who completed all tasks and tests. The results are given in Table 41 . The inverse of the summation gives an indication of the goodness of the test. The ratings for the tests for all three tasks are given below in descending order of merit:

Resistor Task	100 Hue test D.15 Test C.V.A. Test Ishihara Test H.R.R. Test
Capacitor Task	D.15 Test C.V.A. Test 100 Hue Test H.R.R. Test Ishihara Test

Wire-sorting Task	100 Hue Test C.V.A. Test H.R.R. Test D.15 Test Ishihara Test

The 100 Hue test, the Lovibond Colour Vision Analyser and the D.15 test (except for the wire task) give the best overall rating; the Ishihara test and the H.R.R. test both give poor ratings.

A further method of analysis was suggested by the Professor of Statistics at The City University after consultation. The graphs were divided into four quadrants. The dividing lines were set at levels on the basis of experience with the test and tasks used. A vertical division separated data points which to the left represented average to low errors for the clinical test in question, and to the right involved larger errors. The intention here was to separate observers with significant colour vision defects from those with only slight anomalies. The horizontal division separated insignificant errors at the practical task from significant errors. The intention here was to separate those observers who would normally be satisfactory at industrial colour naming tasks from those with a marked industrial handicap. The horizontal division was made at six errors for resistor colour naming, three errors for capacitor colour naming, and zero errors for errors in wire-sorting. This allowed for a small number of errors in colour naming to be due to fatigue and other factors, but assumed that any error in pairing of coloured wires would be significant. The vertical divisions for the standard colour vision tests were made at the following scores:

100 Hue Test	100 errors
C.V.A. Test	120 Range
H.R.R. Test	6.5 errors
Ishihara Test	18 errors
D.15 Test	3.5 errors

Only data for those observers who took part in all tasks and who were tested on all five colour vision tests, was used. The number of data points in each quadrant was summated and a percentage number calculated for each quadrant, together with the standard error for each quadrant. To obtain an indication of the appropriateness of the colour vision test to predict practical ability at the task concerned it is desirable that points should lie in opposite quadrants - namely the bottom left hand and the top right hand quadrants. The percentage number of points lying in these two sectors was calculated as an indication of the goodness of the test - the higher the percentage the better the correlation. The results are given in Table 42 . The ratings for the tests for all three tasks are given below in descending order of merit:

Resistor Task	D.15 Test Ishihara Test 100 Hue Test H.R.R. Test C.V.A. Test
Capacitor Task	D.15 Test 100 Hue Test C.V.A. Test Ishihara Test H.R.R. Test
Wire-sorting Task	100 Hue Test C.V.A. Test H.R.R. Test D.15 Test Ishihara Test.

These results are rather more mixed than the previous methods of analysis used. In particular the Ishihara test is rated well for the resistor task in comparison with other tests, but poorly for the capacitor and wire-sorting tasks as before. Nevertheless the percentages obtained for the resistors are all very similar with the least amount of variation occuring for this group. Overall the 100 Hue Test rates the best and the D.15 is the best test for colour naming, but is poor for the wire-sorting task as before.

Such analysis is, however, open to criticism because the results are very much dependent on where the dividing lines are placed and on observer variability.

It appears from these results that standard colour vision tests are not ideal for predicting the practical ability and potential performance of colour defective observers at industrial colour work. If the use of such a test is desirable, care should be taken to avoid choosing the Ishihara test for this purpose.

TABLE 39a

ELECTRICAL TRIAL RESULTS

Deutan Observers

Number	Wire Sorting	Resistor Naming	Capacitor Naming	100 Hue Score	Ishihara Errors	HRR Errors	Loviband CVA Range	Nagel Range	Nagel Midpoint	D15 Cross
D11		49	26	226	20	13	140	75		12
D24	6	39	31	235	20	12	140	75		10
D 2	2	18	14	202	20	13	140	75		10
D 5	3	18	5	213	20	9	140	75		12
D19	11	32	10	278	20	14	140	75		5
D27	9	28	25	416	17	14	140	75		12
D 4			16	384	20	15	140	75		13
D25		21			20	9	120	75		12
D 8	7	24	5	207	20	11	140	75		10
D28	2	14	19	206	20	10	140	75		12
D21	5	37	25	249	20	12	105	75		9
D12	4	23	30	199	20	13	130	75		7
D22	3	18	7	147	20	6	140	75		11
D17	1	29	29	343	20	11		75		11
D18	4	33	14	265	20	13	140	75		7
D56	0	9	1		10	6	75	18	20	6
D59	0	6	0		20	9	77	14	17	0
D58	0	4	0	83	20	6	90	15	17	2
D39	1	12	4	170	20	11	40	41	20	3
D55	0	0	0	84	11	3	23	18	14	0
D65	0	5	0	121	15	9	70	6	23	2
D61	0	10	4	179	20	5	35	12	11	9
D68	2	3	1	86	16	6	25	5	24	0
D45	0	15	3		20	10		35	29	7
D41	0	9	4	173	20	8	25	40	20	7
D66	0	2	0	95	13	4	30	6	28	0
D36	2	13	4	206	20	8	110	43	21	10
D42	0	9	0	204	20	6	140	38	19	2
D32	10	34	19	273	16	9	140	47	24	8
D46	1	21	7	191	20	12	90	35	17	9
D48	0	1	0	104	18	8	70	30	15	0
D51	0	4	0	25	7	2	135	19	15	0
D47	3	1	0	134	20	14	140	34	40	6
D37	0	11	1		20	12		42	21	8
D43	1	2	2	272	20	6	50	36	18	4
D62	0	2	0		5	2		12	14	0
D57	0	2	2	83	20	11	70	15	17	0

TABLE 39b
ELECTRICAL TRIAL RESULTS

Protan Observers

Number	Wire Sorting	Resistor Naming	Capacitor Naming	100 Hue Score	Ishihara Errors	HRR Errors	Loviband CVA Range	Nagel Range	Nagel Midpoint	D15 Cross
P11	0	15	14	70	20	6	140	75		10
P 9	2	29		332	20	8	140	75		13
P10	3	22	34	164	20	12	140	75		10
P 2	3	26	16	189	20	12	140	75		12
P 6		18		128	20	11	140	75		13
P 5	0	10	4	109	19	11	140	75		7
P 3	4	24	30	149	20	8	140	75		11
P 8	5	19	25	259	20	14	140	75		11
P 1	4	34	28	163	20	11	135	75		13
P 4	6	30	24	186	20	12	140	75		11
P12	3	25	17	102	20	11	140	75		8
P19	2	19	2	149	20	14	135	20	50	0
P21	0	1	1	107	9	11	40	16	54	2
P23	0	13	0	56	19	14	25	15	57	7
P20	0	23		121	20	11	50	18	53	2
P25	0	7	2	66	16	4		3	62	1
P17	0	1	0	32	20	12	45	65	32	2

Task and Test	Coefficient correlation	Gradient	Intercept on y axis
Resistors + 100 Hue	0.634	0.0937	1.48
Capacitors + 100 Hue	0.558	0.069	-1.089
Wires + 100 Hue	0.63	0.0205	1.049
Resistors + HRR	0.525	1.88	-1.604
Capacitors + HRR	0.456	1.44	-3.86
Wires + HRR	0.458	0.37	-1.32
Resistors + Ishihara	0.426	1.404	-9.24
Capacitors + Ishihara	0.352	1.049	-8.99
Wires + Ishihara	0.229	0.171	-0.88
Resistors + CVA	0.613	0.168	-0.739
Capacitors + CVA	0.596	0.147	-4.94
Wires + CVA	0.573	0.036	-1.24
Resistors + D15	0.697	1.844	4.04
Capacitors + D15	0.707	1.77	1.56
Wires + D15	0.473	0.297	0.33

Table 40 Analysis of Electrical Trial Results

Task and Test	Sum of distances from line of best fit.
Resistors + 100 Hue Test	240
Capacitors + 100 Hue Test	323
Wires + 100 Hue Test	60
Resistors + HRR Test	427
Capacitors + HRR Test	365
Wires + HRR Test	77
Resistors + Ishihara Test	369
Capacitors + Ishihara Test	408
Wires + Ishihara Test	95
Resistors +CVA Test	308
Capacitors + CVA Test	278
Wires + CVA Test	73
Resistors + D15 Test	253
Capacitor + D15 Test	252
Wires + D15 Test	83

Table 41 Deviations from line of best fit for different electrical tasks and colour vision tests

Task	Ishihara	CVA	HRR	100 Hue	D15
Resistor	83% ±5.1	76% ±6.3	77% ±5.6	79% ±5.9	87% ±4.6
Capacitor	75.4% ±5.9	78% ±6.1	72% ±6.2	83% ±5.5	88% ±4.6
Wires	70% ±6.4	77% ±6.3	68% ±6.4	80.5% ±5.8	64% ±6.8

Table42 Percentage of points in two disjoint boxes for electrical graphs

FIG 23

RESISTOR ERRORS PLOTTED AGAINST 100 HUE TEST ERRORS

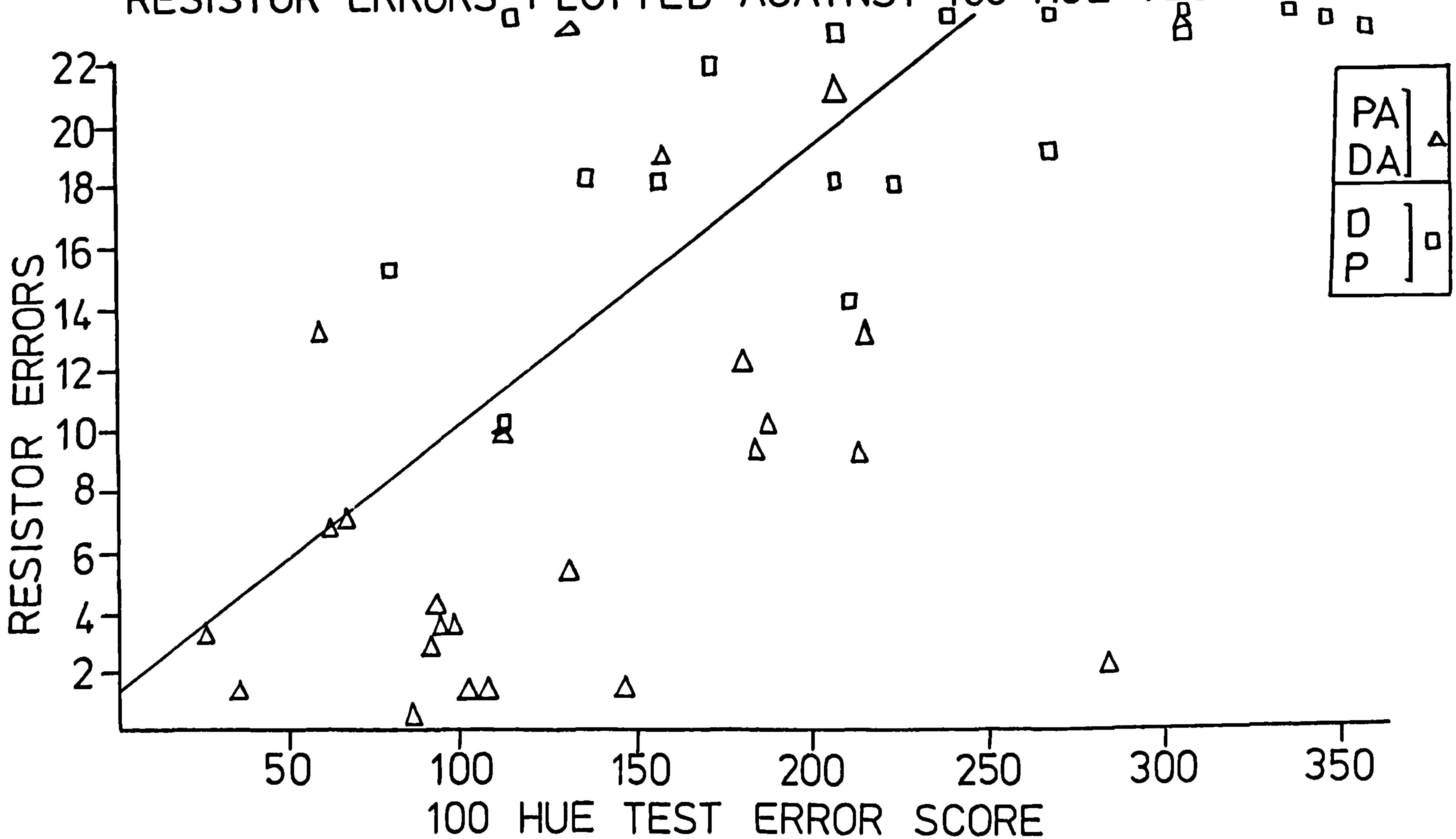


FIG 24

CAPACITOR ERRORS AGAINST 100 HUE TEST ERRORS

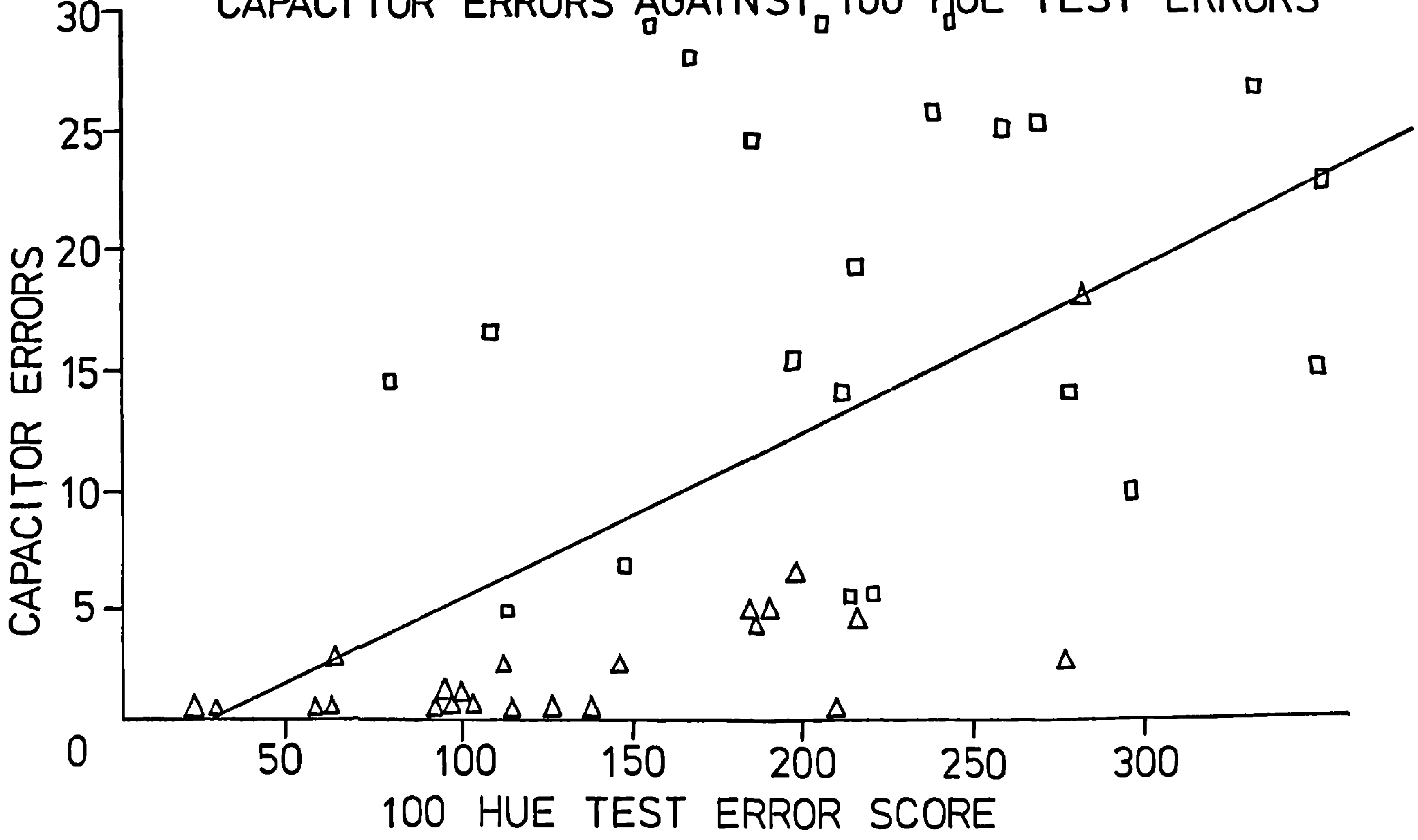


FIG 25

WIRE SORTING ERRORS AGAINST 100 HUE TEST ERRORS

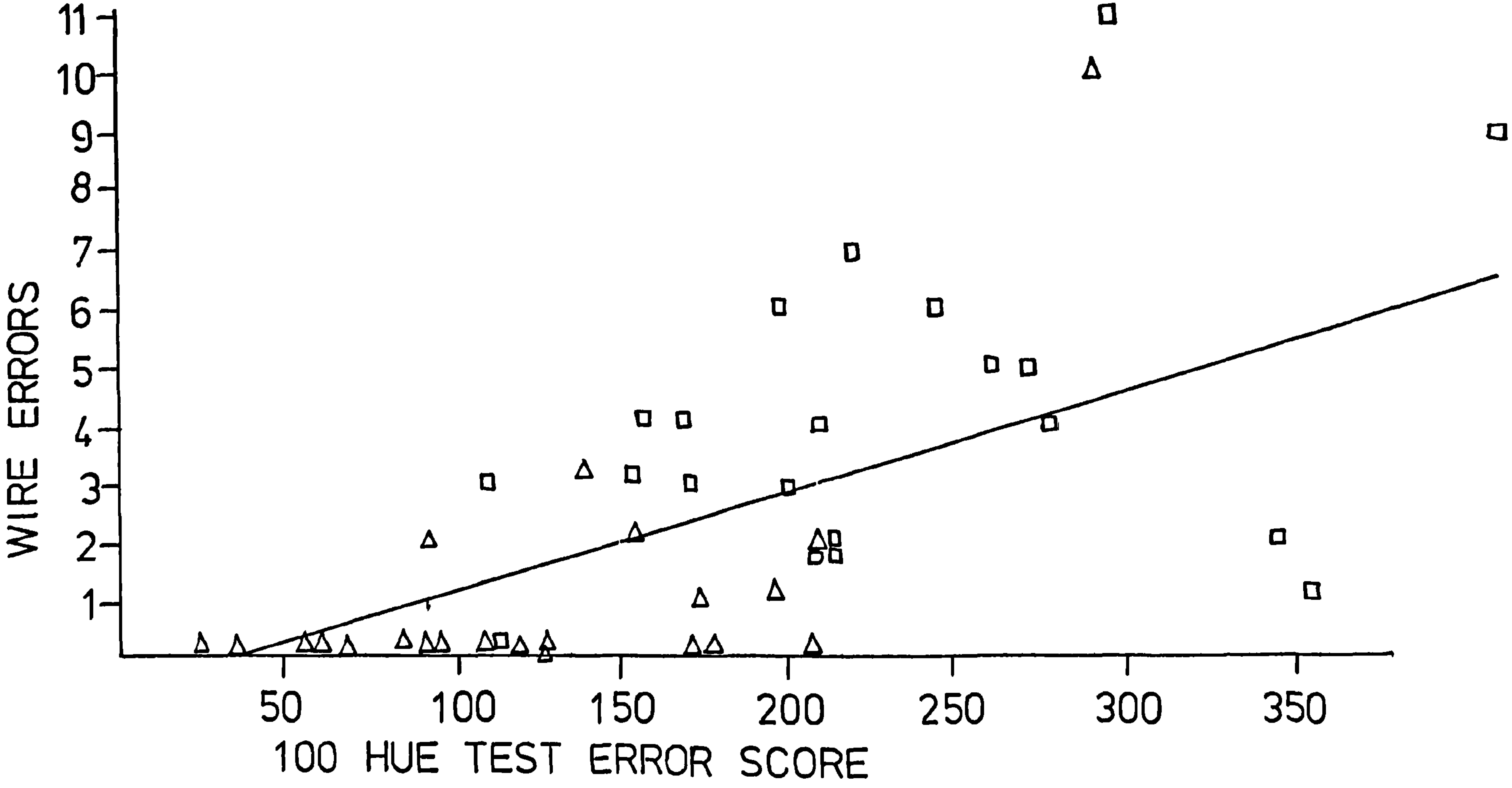


FIG 26

RESISTOR ERRORS AGAINST LOVIBOND TEST RANGE

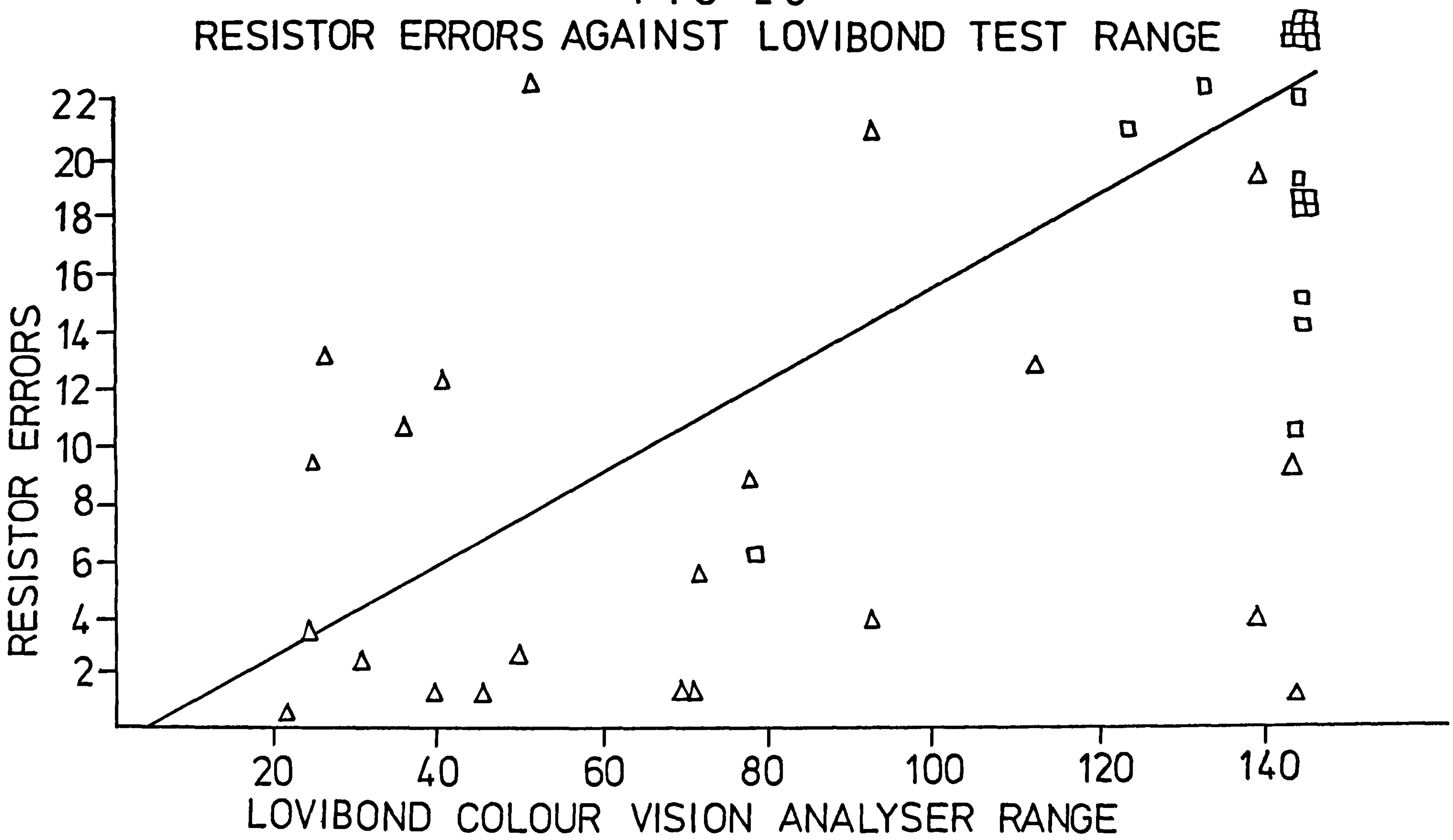


FIG 27

CAPACITOR ERRORS AGAINST LOVIBOND TEST RANGE

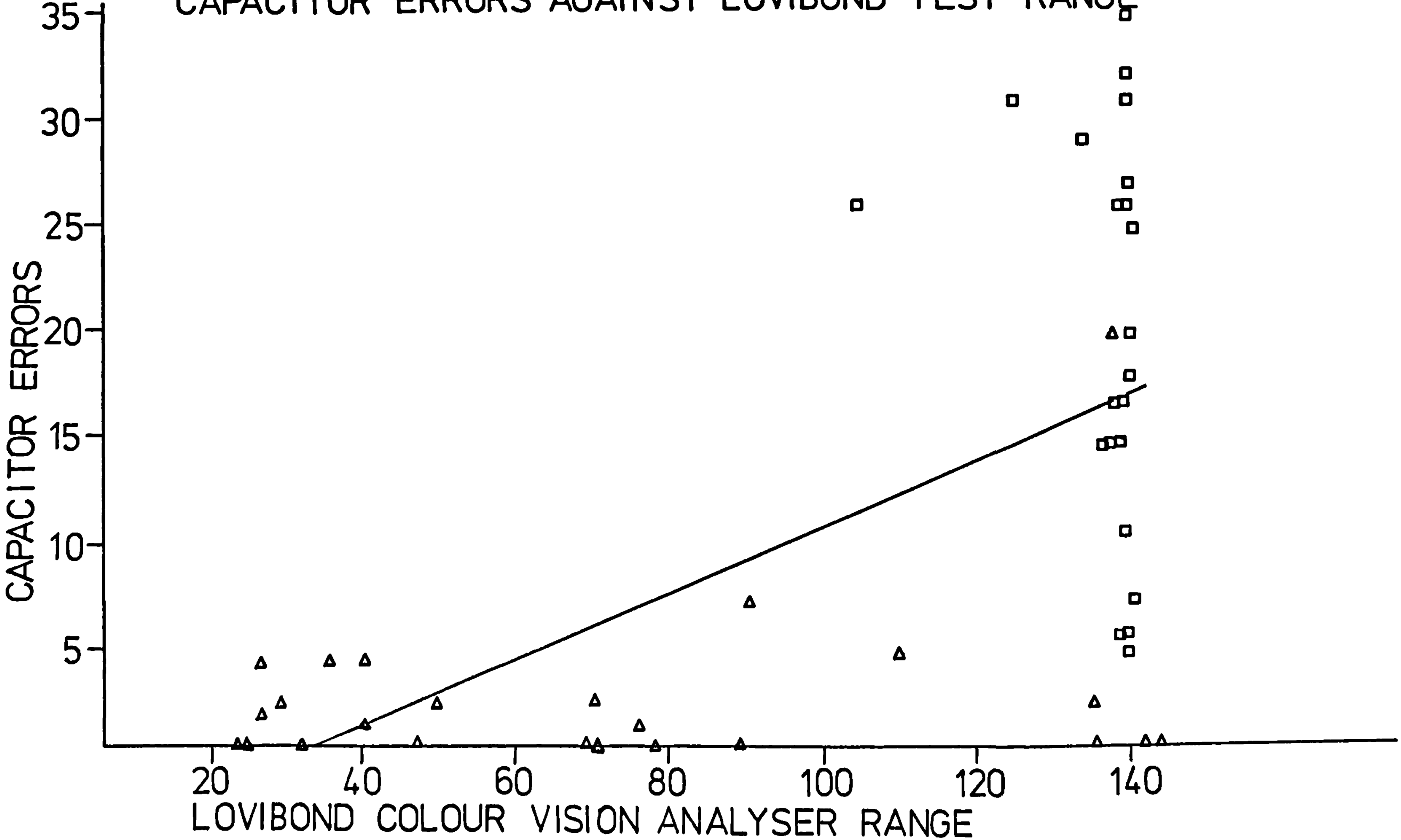


FIG 28

WIRE ERRORS AGAINST LOVIBOND TEST RANGE

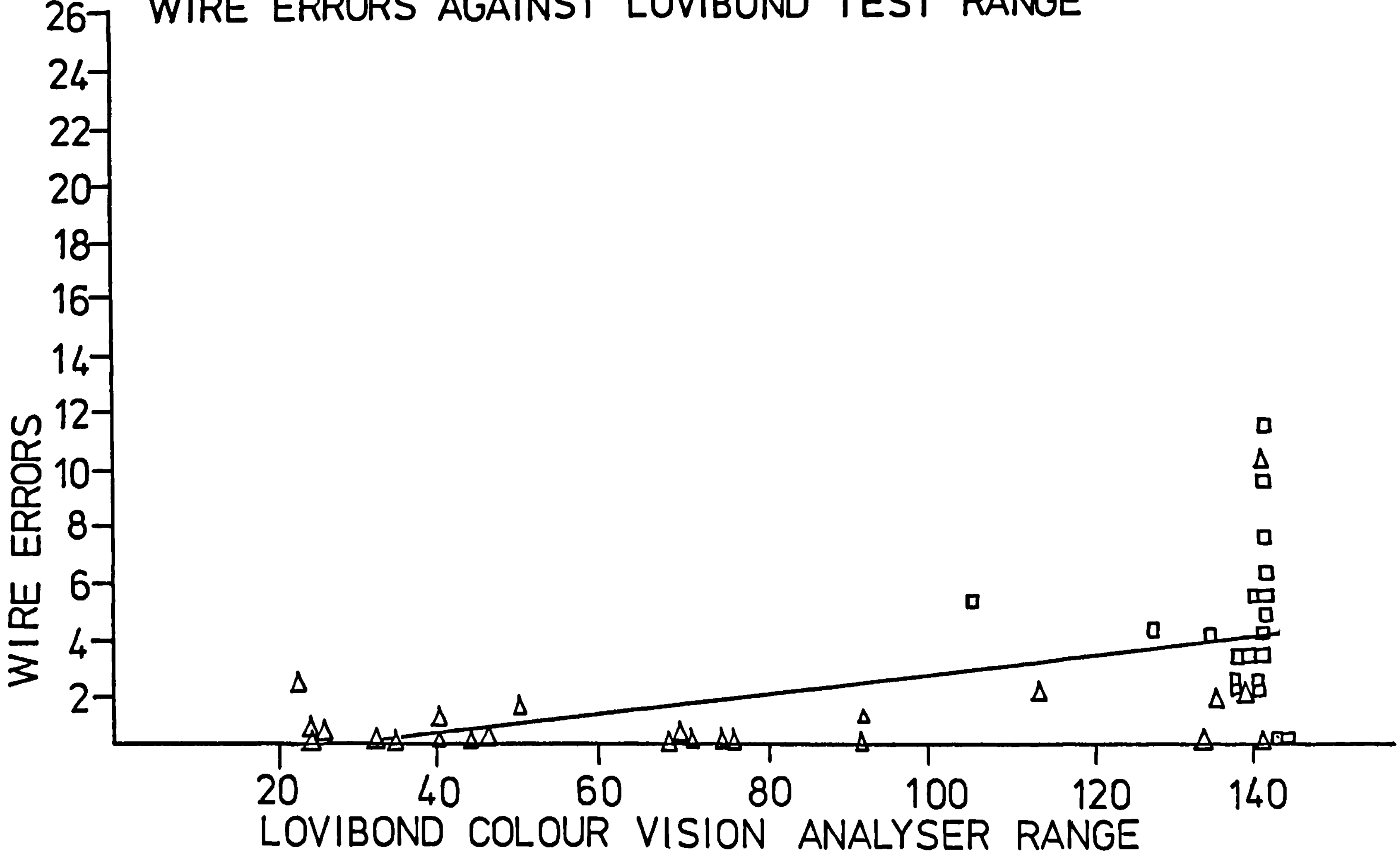
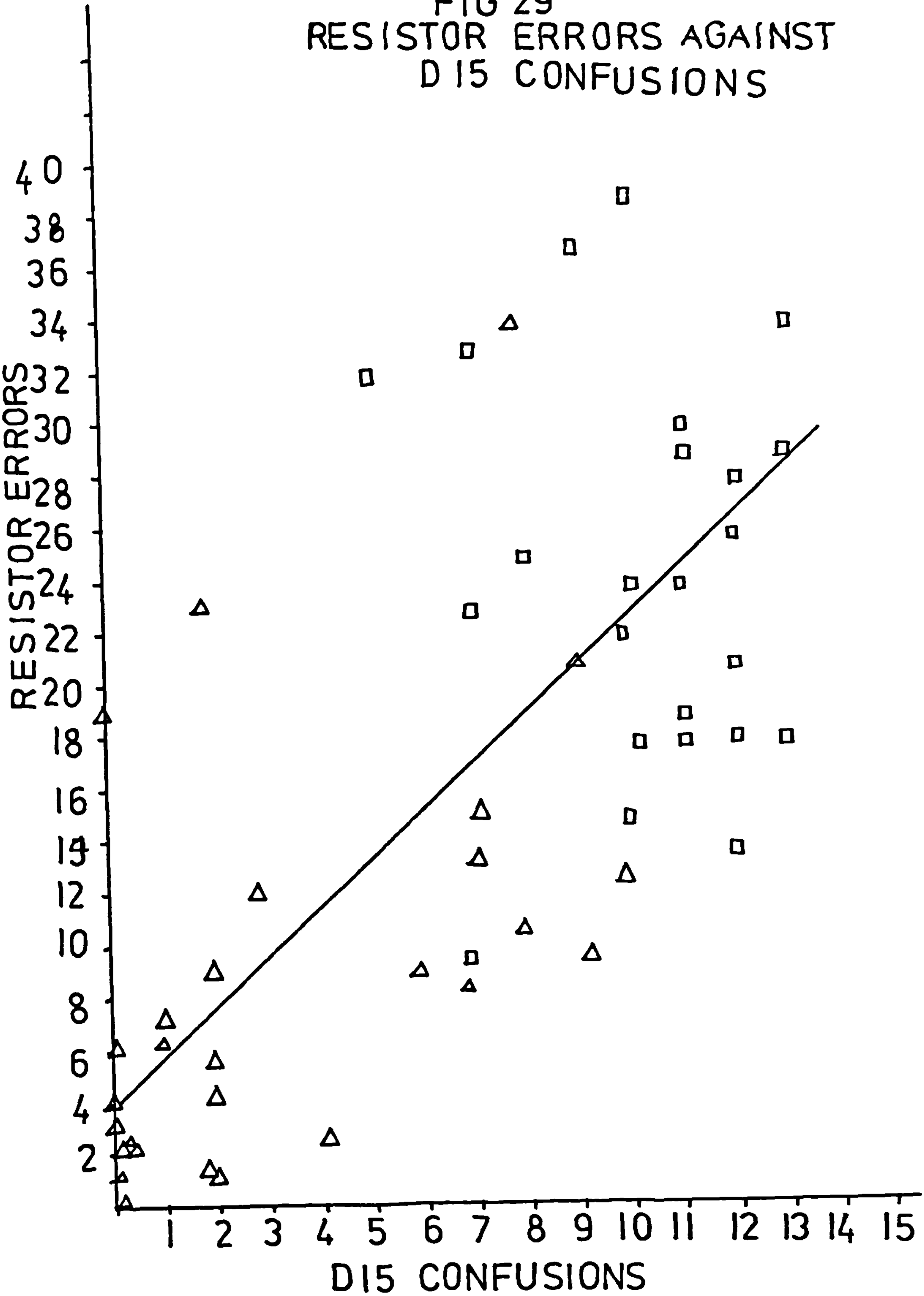


FIG 29
RESISTOR ERRORS AGAINST
D15 CONFUSIONS



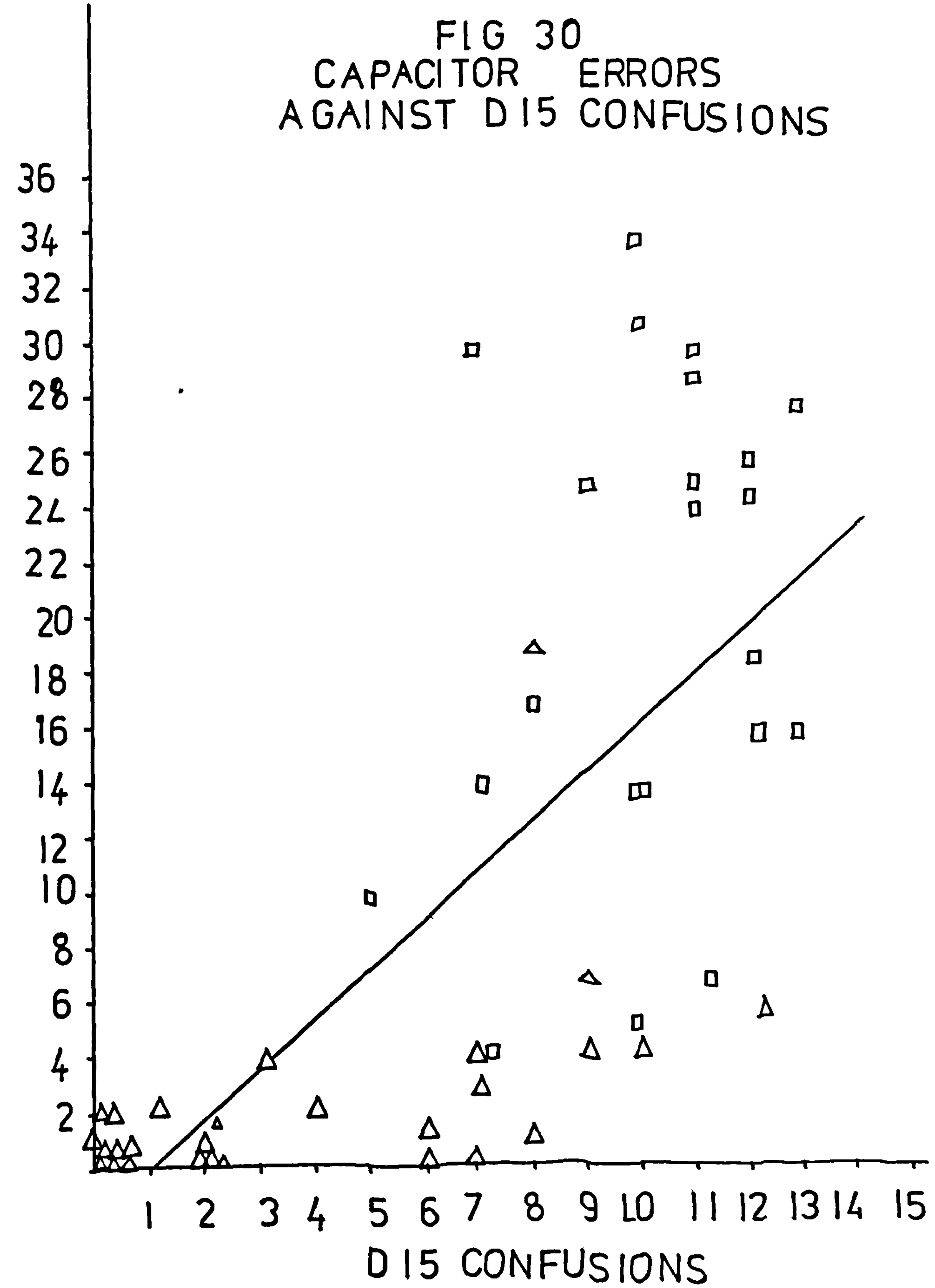


FIG 30
CAPACITOR ERRORS
AGAINST D15 CONFUSIONS
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
D15 CONFUSIONS

FIG 31
WIRE SORTING ERRORS
AGAINST D 15 CONFUSIONS

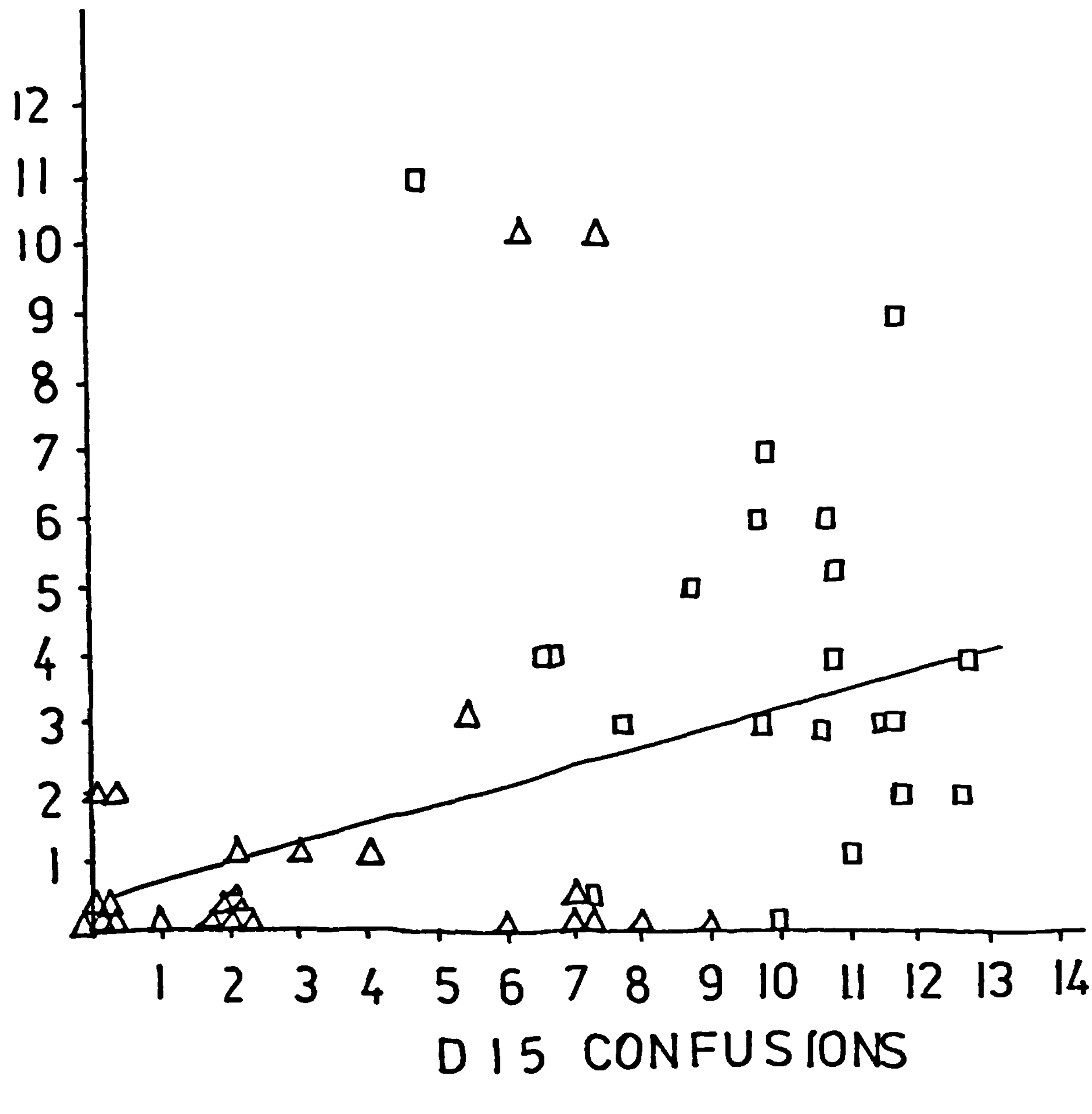


FIG 32
RESISTOR ERRORS AGAINST HRR TEST

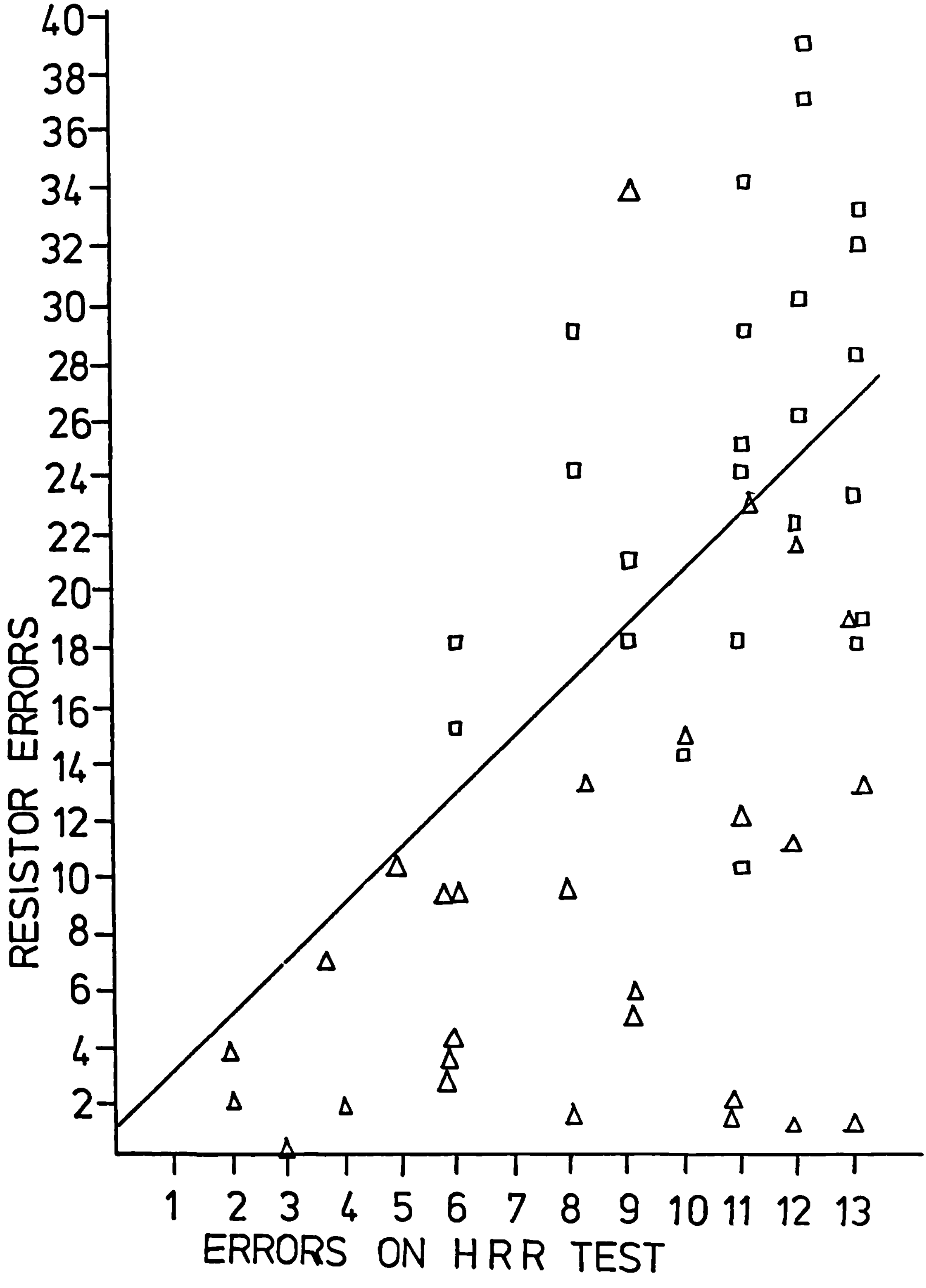


FIG 33
CAPACITOR ERRORS AGAINST HRR TEST

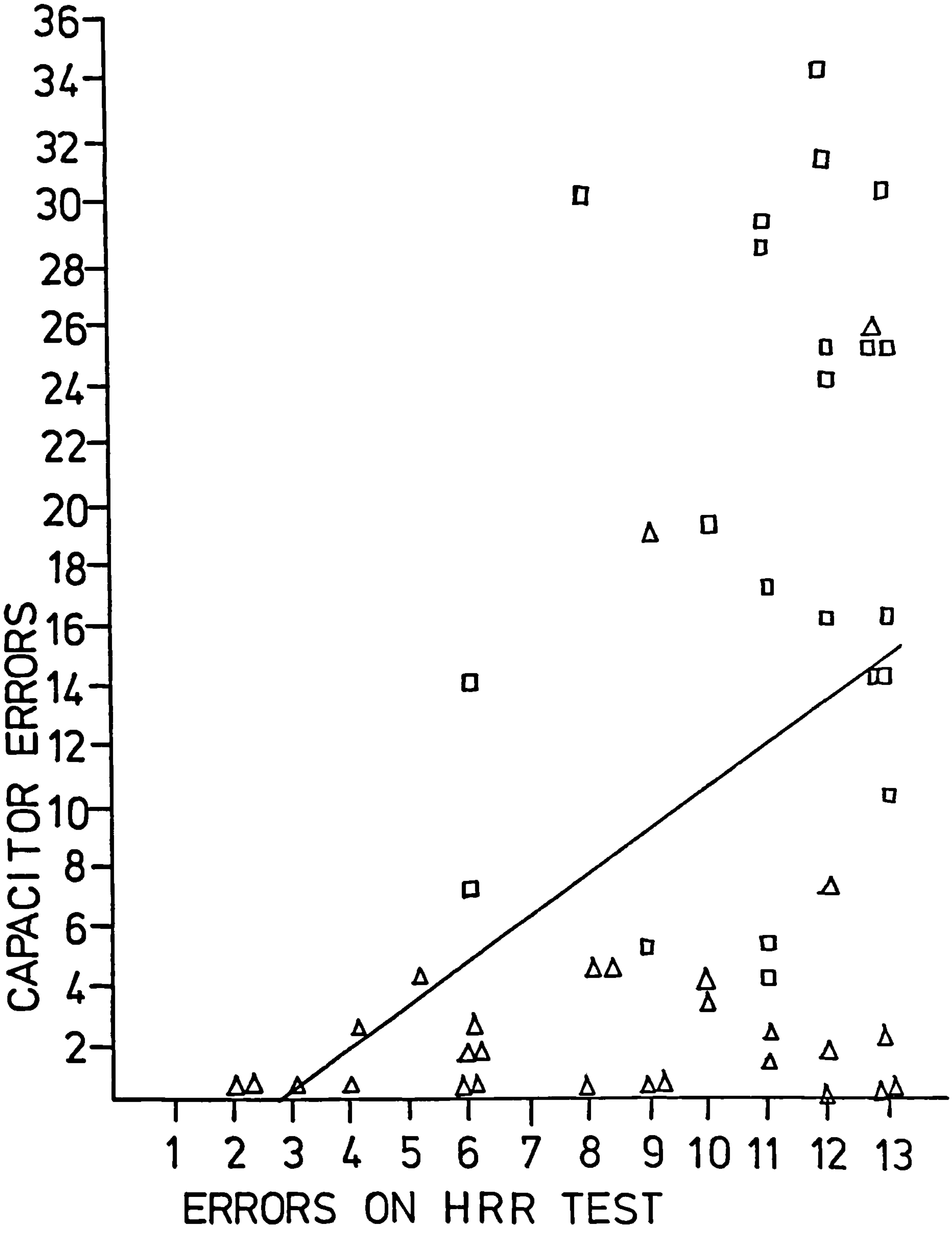


FIG 34

WIRE ERRORS AGAINST HRR TEST

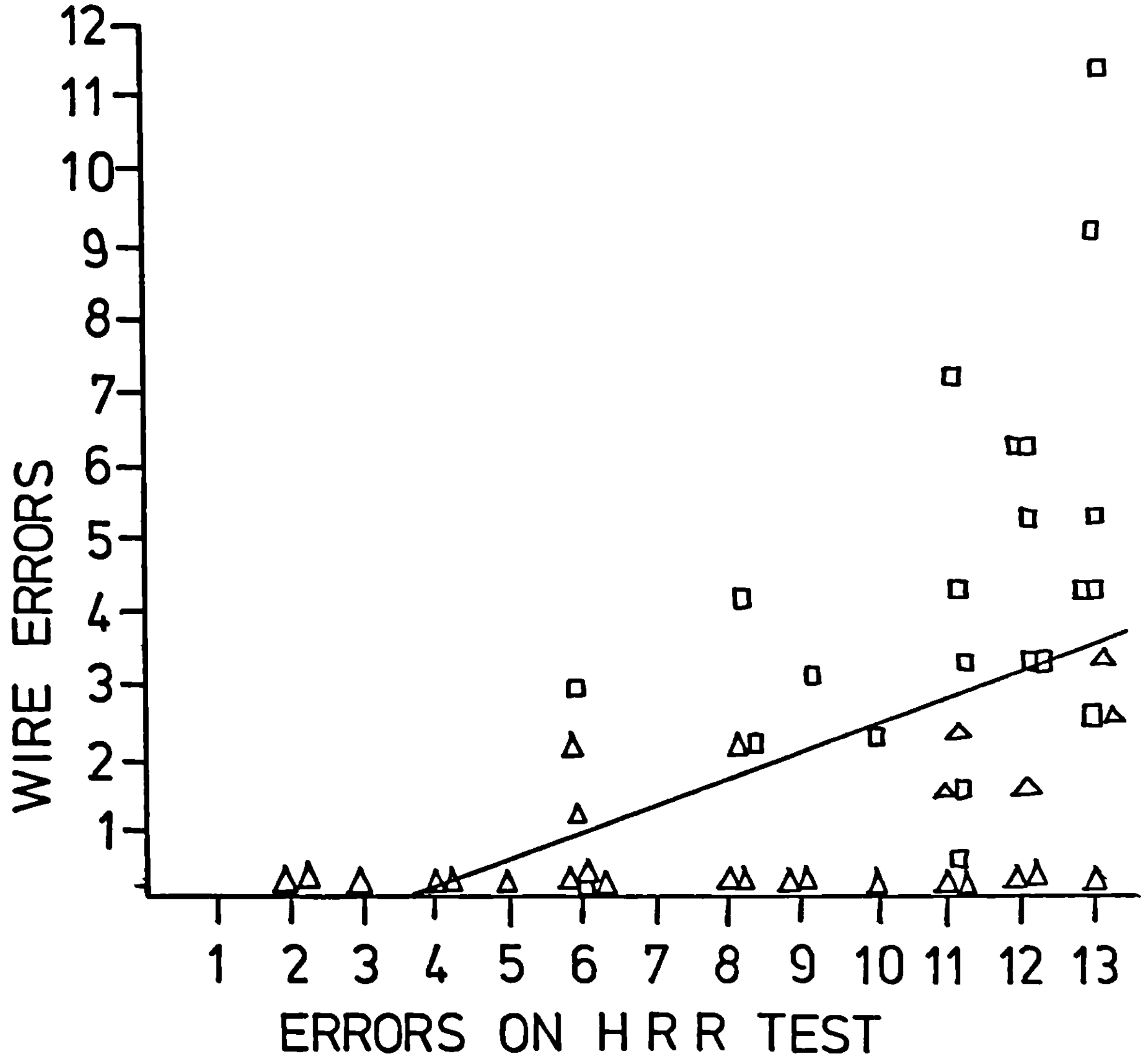


FIG 35

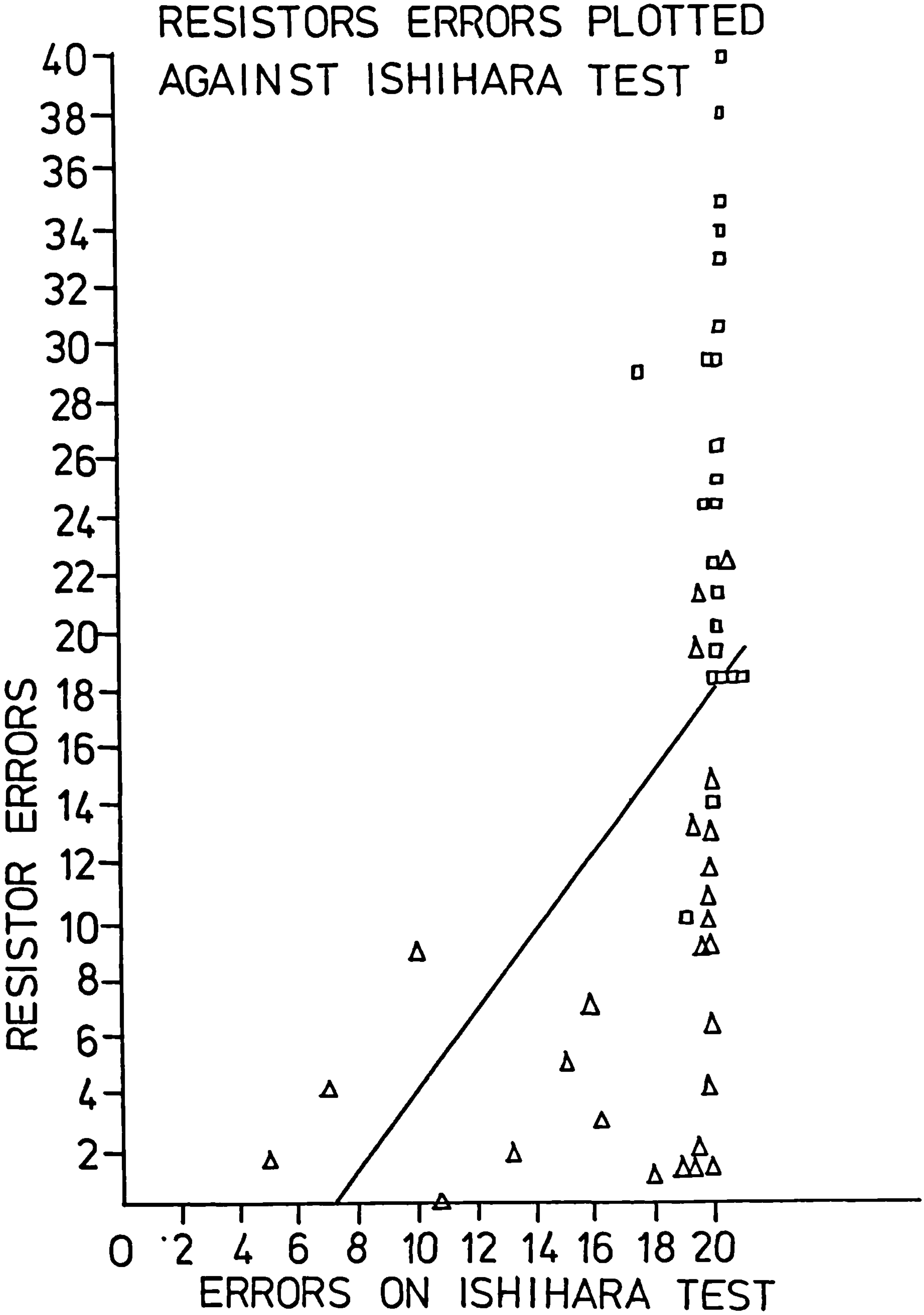
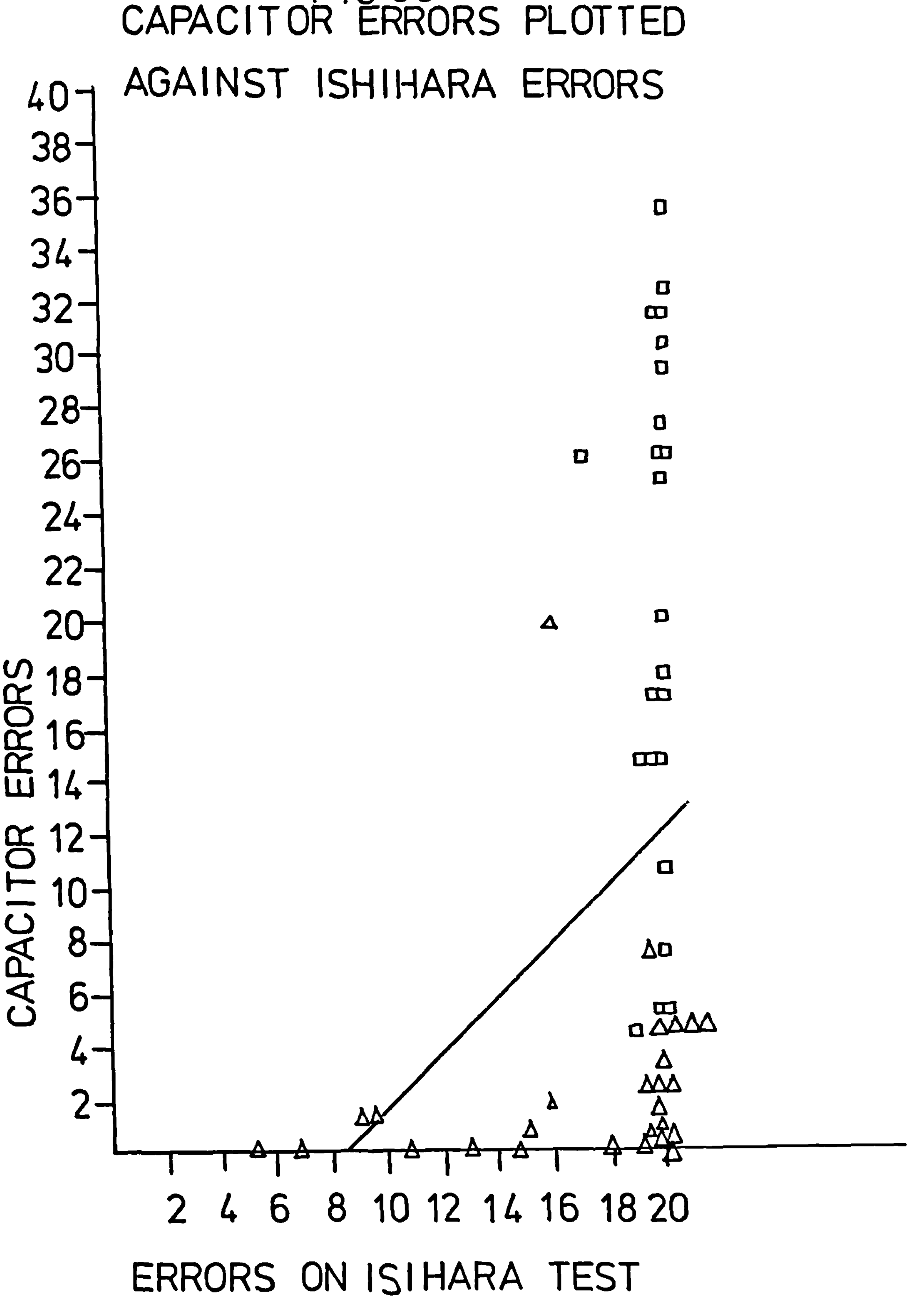

RESISTORS ERRORS PLOTTED
AGAINST ISHIHARA TEST
RESISTOR ERRORS
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0 2 4 6 8 10 12 14 16 18 20
ERRORS ON ISHIHARA TEST

FIG 36


CAPACITOR ERRORS PLOTTED
AGAINST ISHIHARA ERRORS
CAPACITOR ERRORS
40
38
36
34
32
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28
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24
22
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12
10
8
6
4
2
2 4 6 8 10 12 14 16 18 20
ERRORS ON ISIHARA TEST

FIG 37
WIRE SORTING ERRORS PLOTTED AGAINST ISHIHARA ERRORS

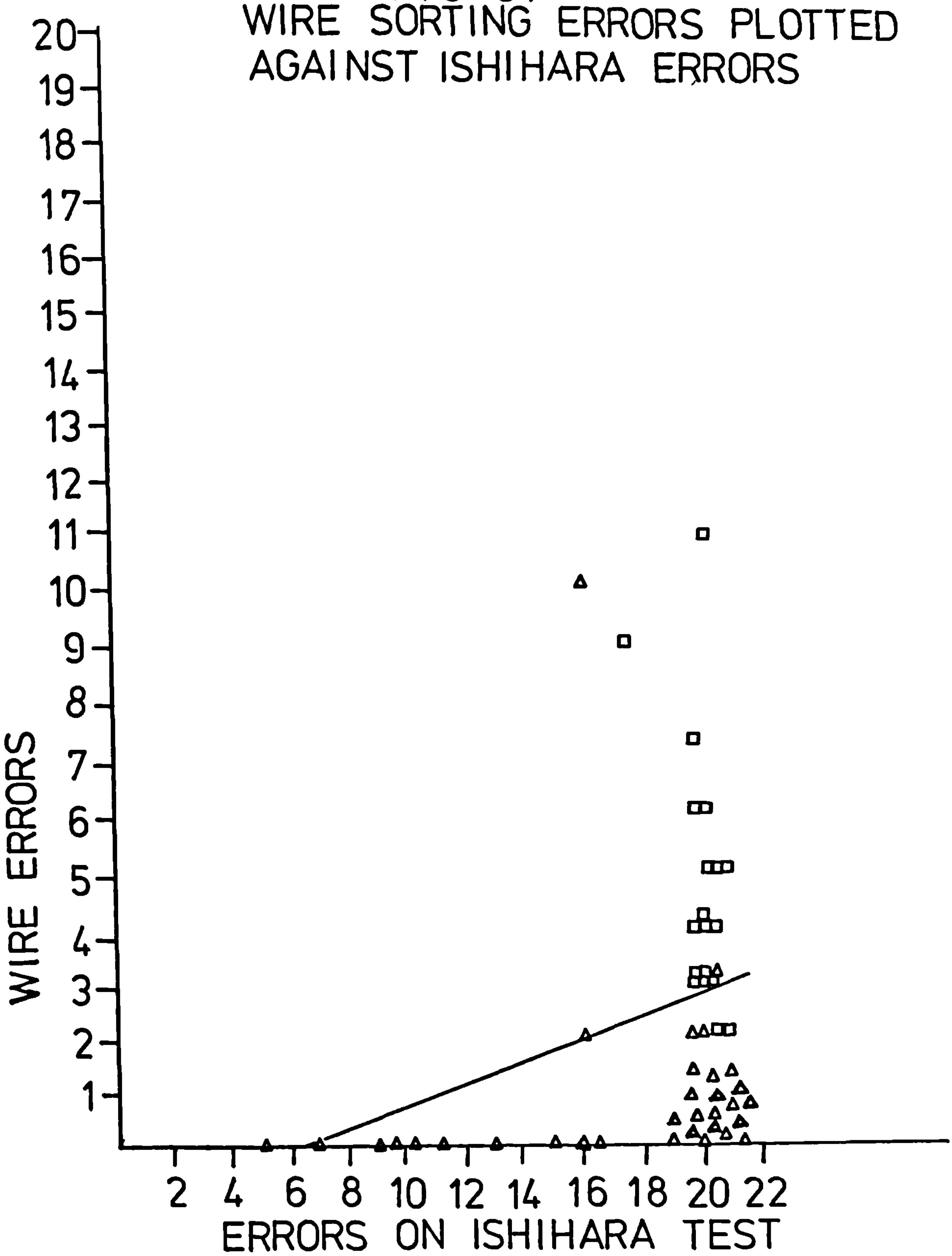


FIG 38

RESISTOR ERRORS AGAINST NAGEL RANGE

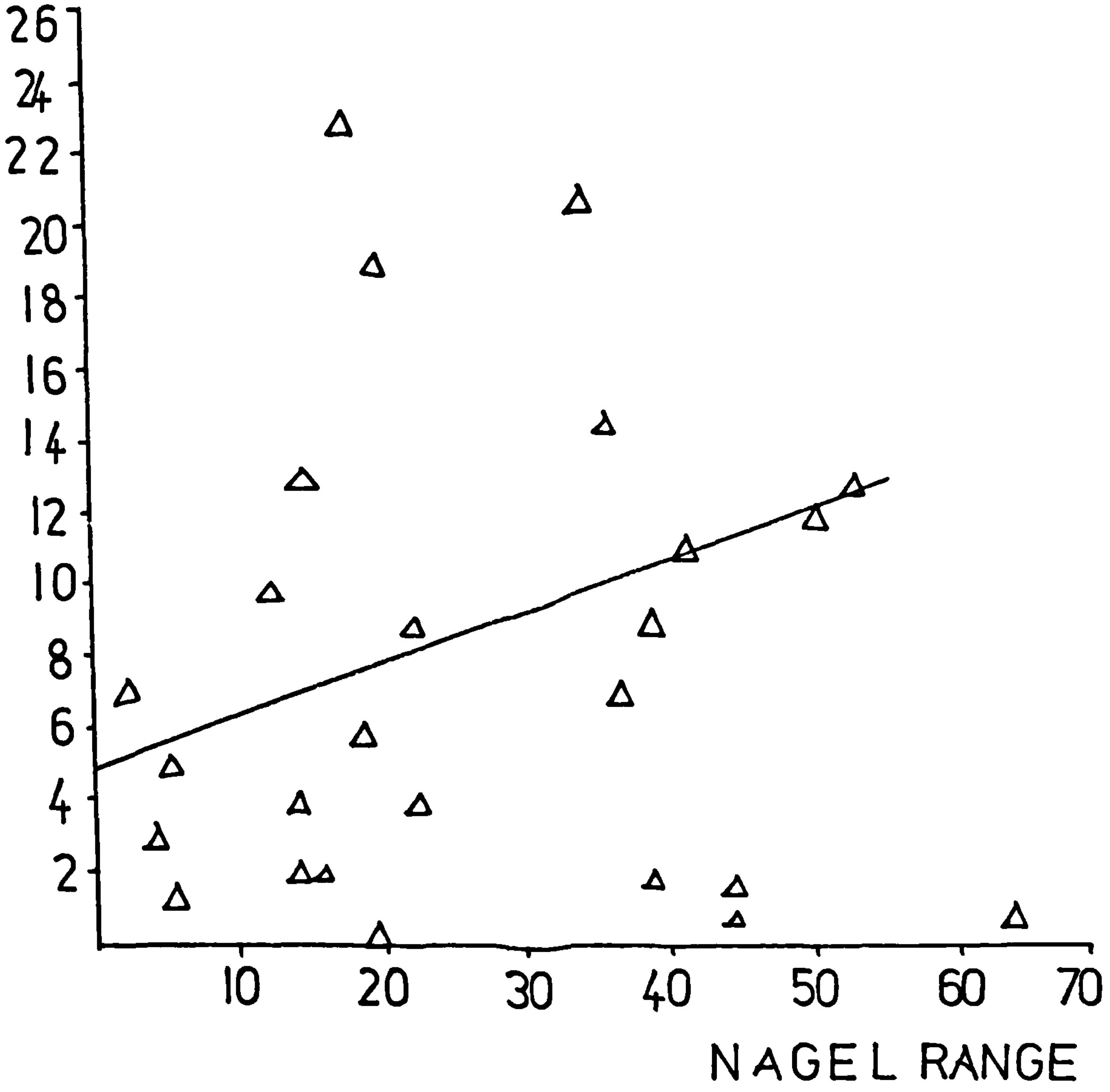


FIG 39
CAPACITOR ERRORS AGAINST
NAGEL RANGE

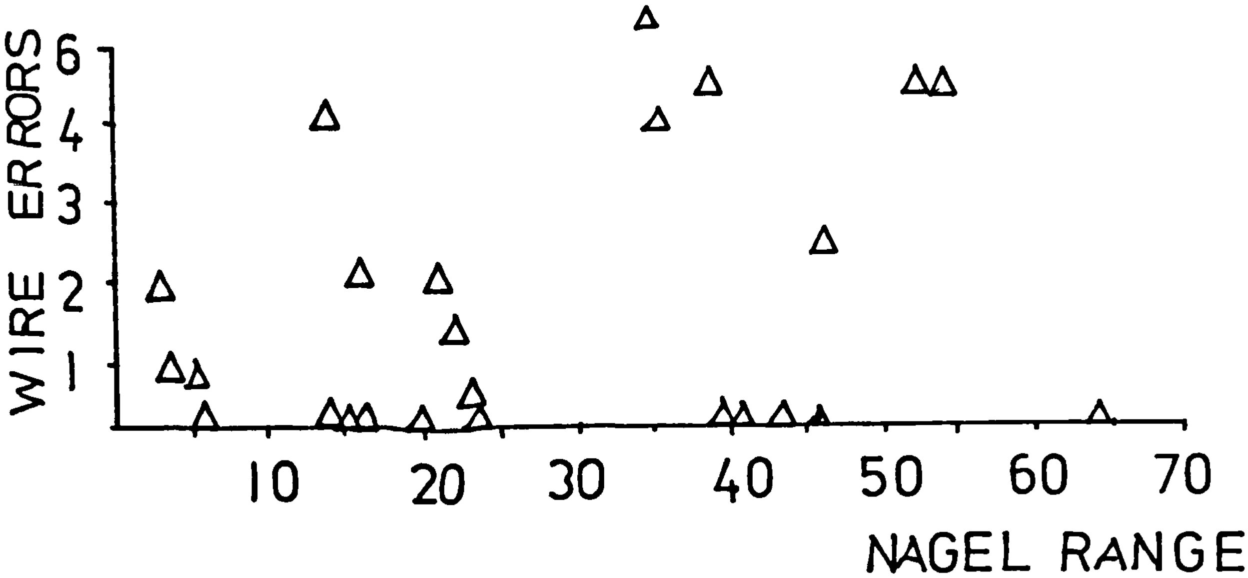


FIG 40
WIRE ERRORS AGAINST
NAGEL RANGE

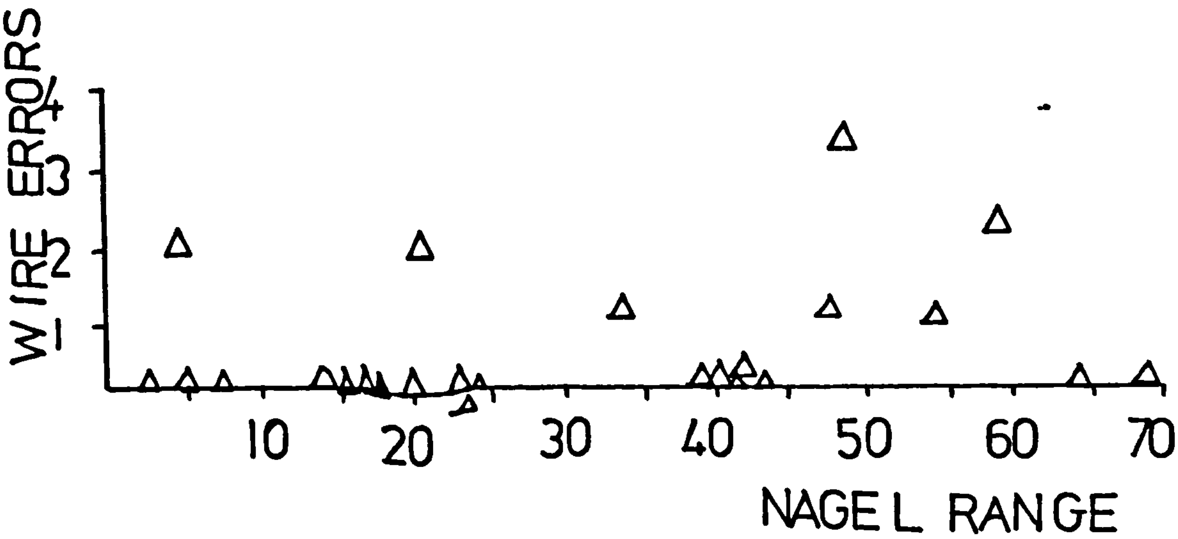


FIG 41
RESISTOR ERRORS AGAINST AGE OF OBSERVERS

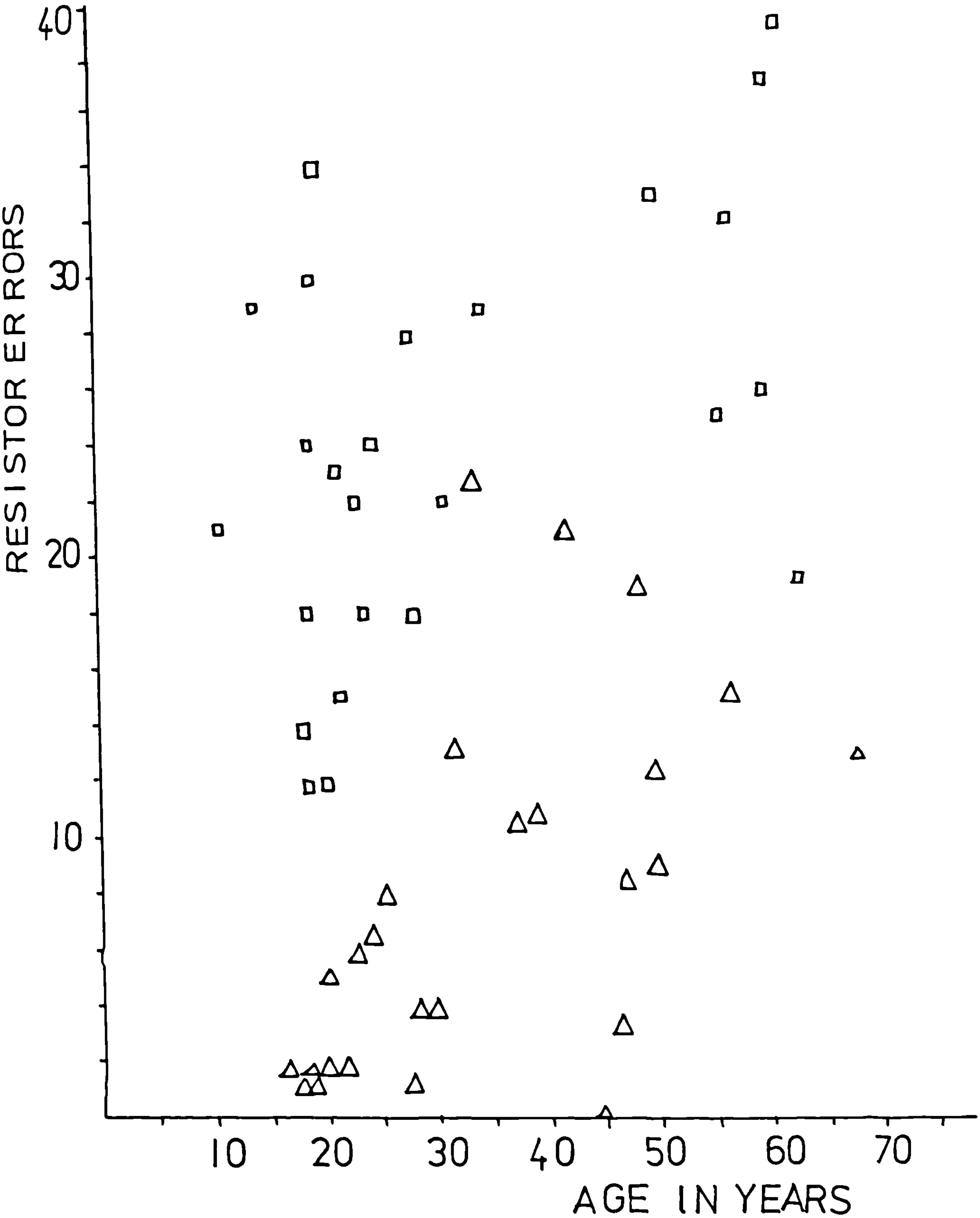


FIG 42
CAPACITOR ERRORS AGAINST
AGE OF OBSERVERS

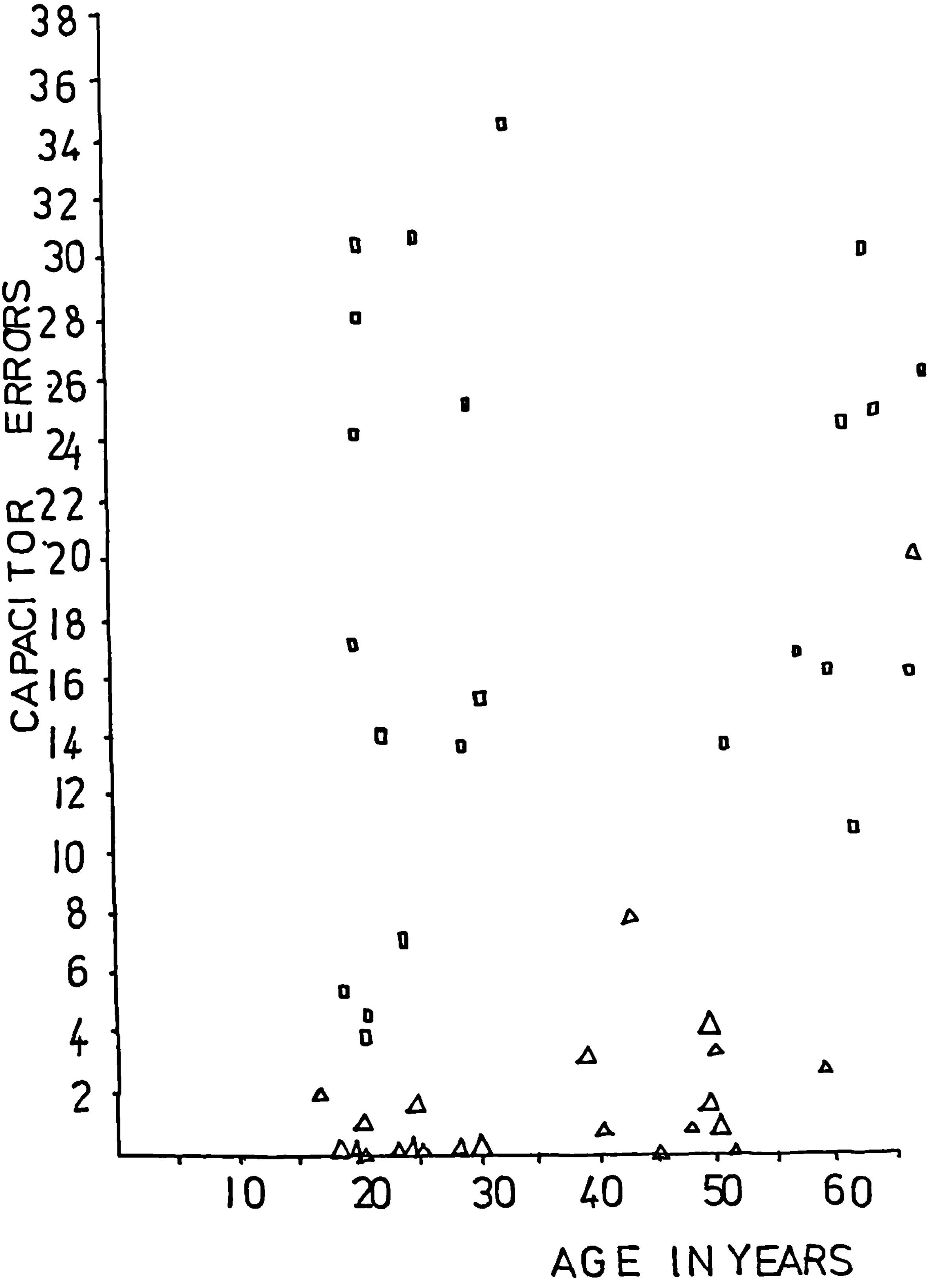
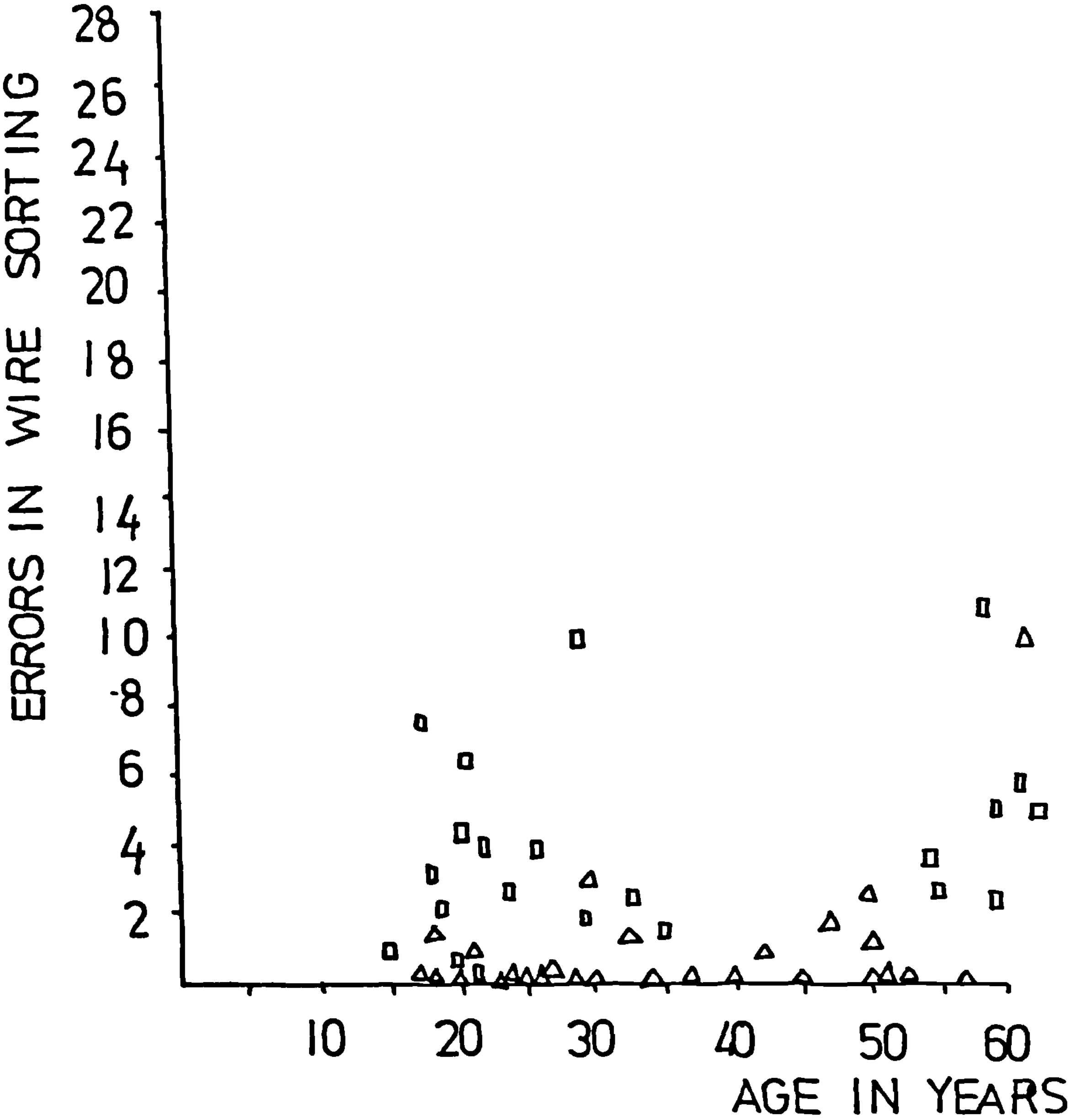


FIG 43
WIRE ERRORS AGAINST
AGE OF OBSERVERS



SECTION IV.4

PHOTOFINISHING TRIAL

Introduction and Aims

Two similar tasks were designed to test the ability of colour defective observers and control colour normals at arranging colour photographic prints in a colour order or sequence to determine whether or not they were able to identify small colour differences or bias in colour photographs and grade successfully according to colour. The tasks closely resembled those required of a photo-finisher in the colour photographic industry.

The material for the trial was kindly supplied by Kodak Research Laboratories, Harrow. Thirty prints were chosen from the thirty-seven print "ring around" series produced by Kodak. Six of the thirty chosen had an extreme colour bias, one each for the colours red, magenta, blue, Cyan, green and yellow, and these six prints were arranged in a hexagon and fixed to a large sheet of white cardboard. Twelve prints showed an intermediate bias between the extreme colours, i.e. two between red and magenta, two between magenta and blue etc. one of which was nearer the red biased print and the other closer to the magenta print, etc. These were also attached to the cardboard.

One print, which appeared the most natural, according to the interpretation of a group of colour normal photo-finishers at Kodak had the ideal colour proportions with no definate colour bias. This print was fixed at the centre of the hexagon.

The remaining twelve prints, representing colour bias intermediate between the fixed extreme colour prints and the central "ideal" print, were presented loose in random order to the observers. Boxes were drawn on the cardboard sheet indicating the positions of the remaining prints. The observers were instructed to place the loose prints in the positions of the boxes where they thought they fitted best, so that a clear progression was made from the central "ideal" colour proportioned print to the corners where the heavily colour biased prints lay. Of the twelve loose prints two had a magenta bias, two a red bias, two a blue bias, two a green bias, two a yellow bias and two a cyan bias. In each of the pairs one was heavily biased towards the colour extreme and the other was less heavily coloured.

<u>Conditions</u>

Owing to the size of the cardboard mounting the observers carried out the task at arm's length, although closer examination was possible, and was in fact encouraged. In the industrial situation colour finishers and those involved in "touching-up" colour prints use a very variable working distance which may vary from a few centimetres to a metre. The prints were size 8cm x 8cm with a gloss finish. Two sets were used, one of a harbour scene predominating in blues, the major area of the print being devoted to blue sky and blue sea. It had the advantage of a near-neutral coloured house face. The second set involved a market scene with a wider range of coloured objects including several people.

Illumination of prints

Specification for artificial daylight assessment of colour in the graphic arts industry is given in B.S. 950 Part 2 (1967). A correlated colour temperature of 5000K is recommended and the level of illumination for viewing by reflection is suggested to be not more than 3229 lux and not less than 753.5 lux. The characteristics of the task illuminant were 6300°K and 700 lux.

Most observers performed the two similar tasks three times each, without being given any indication of their performance or accuracy. A positive encouragement was given before the third attempt at each scene to avoid carelessness due to boredom. It was evident that a total of six attempts was about the maximum that most observers could tolerate without undue fatigue and loss of motivation, although further attempts were made by a few observers selected for their patience and perseverance. Some observers were over-conscientious with the task and took up to eight minutes. Uncertainty and hesitancy in placing the prints was displayed by approximately seventy percent of the colour defective observers, and a complete change ofmind was not uncommon. Some were still unsatisfied with their placements at the end of several minutes, but felt they could do no better and were therefore encouraged to do their best. The task was not easy for a colour normal so that it provided considerable difficulty for some colour defectives.

The sample

Forty-two colour defectives took part in the trial. Of these five were restricted in the time available to do the task and only completed one attempt at each scene. One additional observer performed only one scene once.

Of the sample, three were protanopes, seven protanomalous, nine deuteranopes, twenty-two deuteranomalous.

Results

As well as a quantitative estimation of errors made by giving a score to each attempt based on the number of displacements of the prints from their correct positioning, a qualitative assessment of errors was made for each group of colour defective observers.

Quantitative assessment of errors

A score was made of each error by the length of minimum path between the chosen position of the print and the correct position according to the plan in Fig 44/Table 50 each interchange shown correspo/nding to path length one. A total was made of the number of unit adjacent interchanges to give the score for that print. Each print has an effective or average maximum score of three giving an overall maximum of thirty-six. (The score may be four for some prints, but this will be compensated by a score of two elsewhere.) To assess the overall performance of observers at the task a percentage score was calculated by taking the fraction of errors made by each observer and multiplying this by one hundred.

e.g. $\frac{25}{36} \times 100$ = Average percentage

The performance of the average observer for each group of colour defectives was also found

e.g. $\frac{25\% + 34\% + ...}{\text{number of observers}}$

The results are given in Tables 46/7 and the data plotted in graphical form in fig. 50 .

Qualitative assessment of errors

The result sheets were examined to investigate the main

PRINTING TRIAL

Name | Date

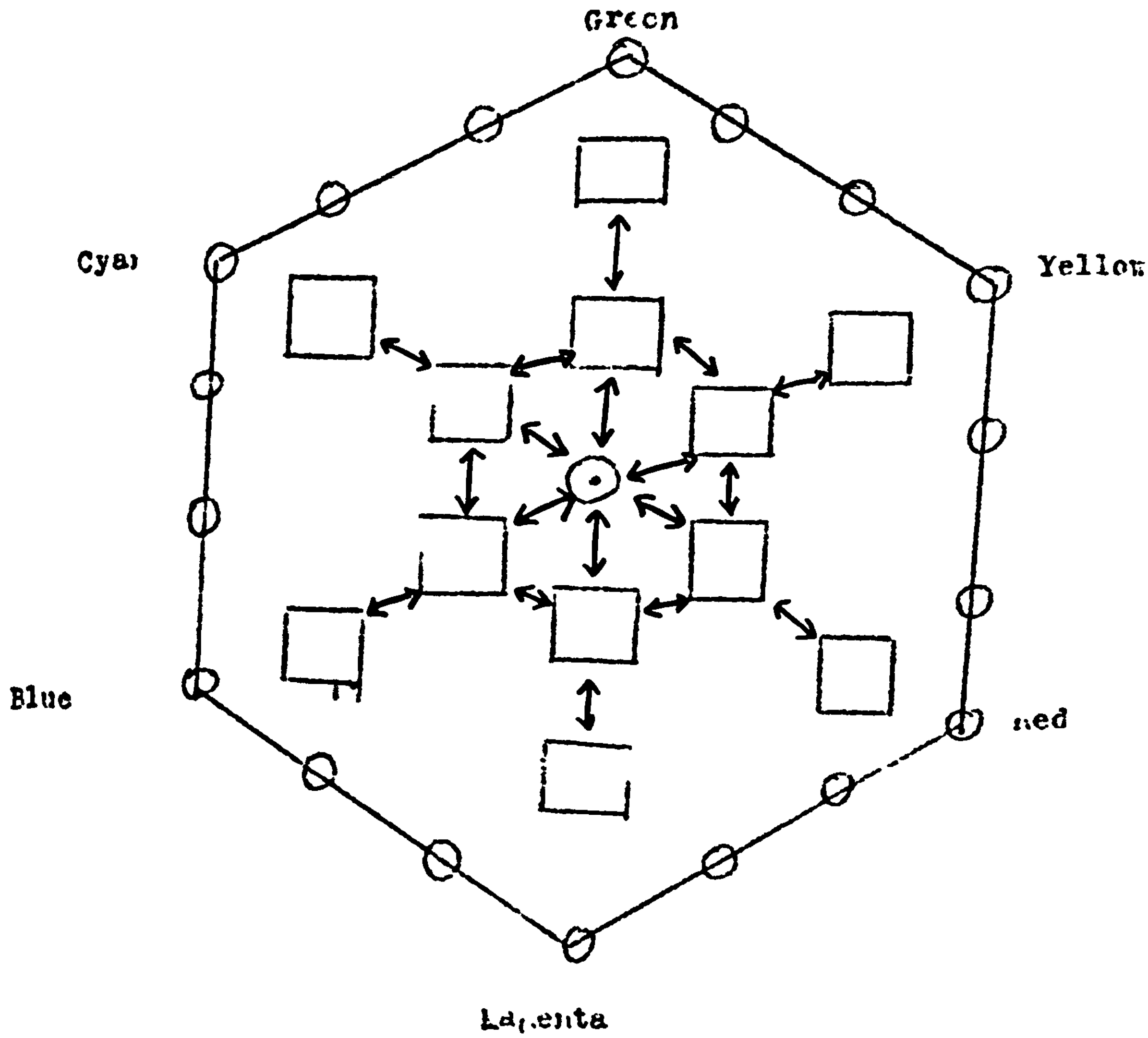


Fig. 44 To show method of scoring used

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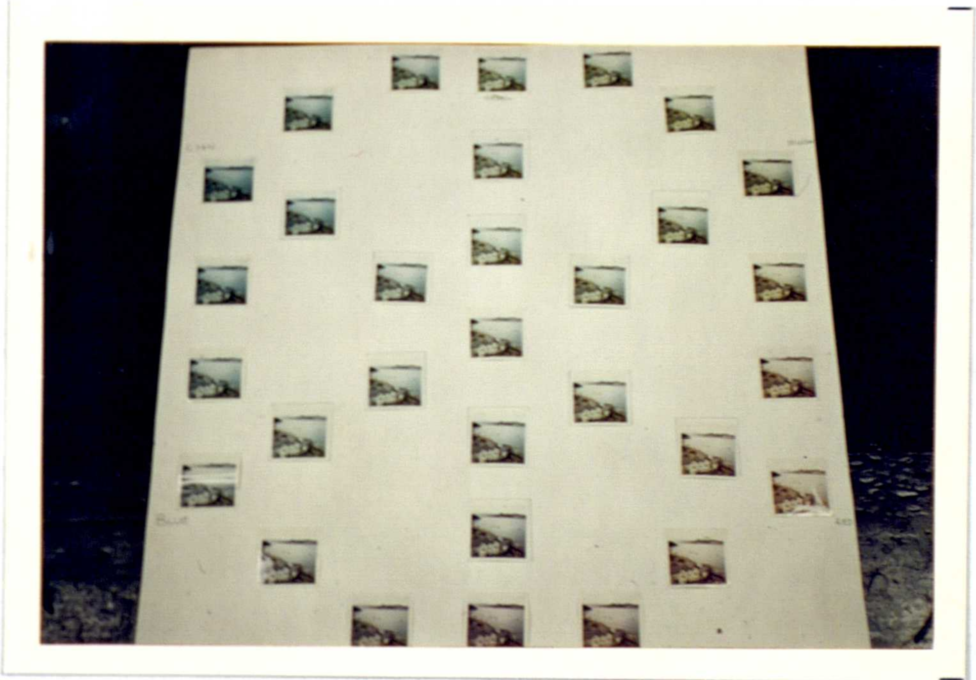
Printing Trial

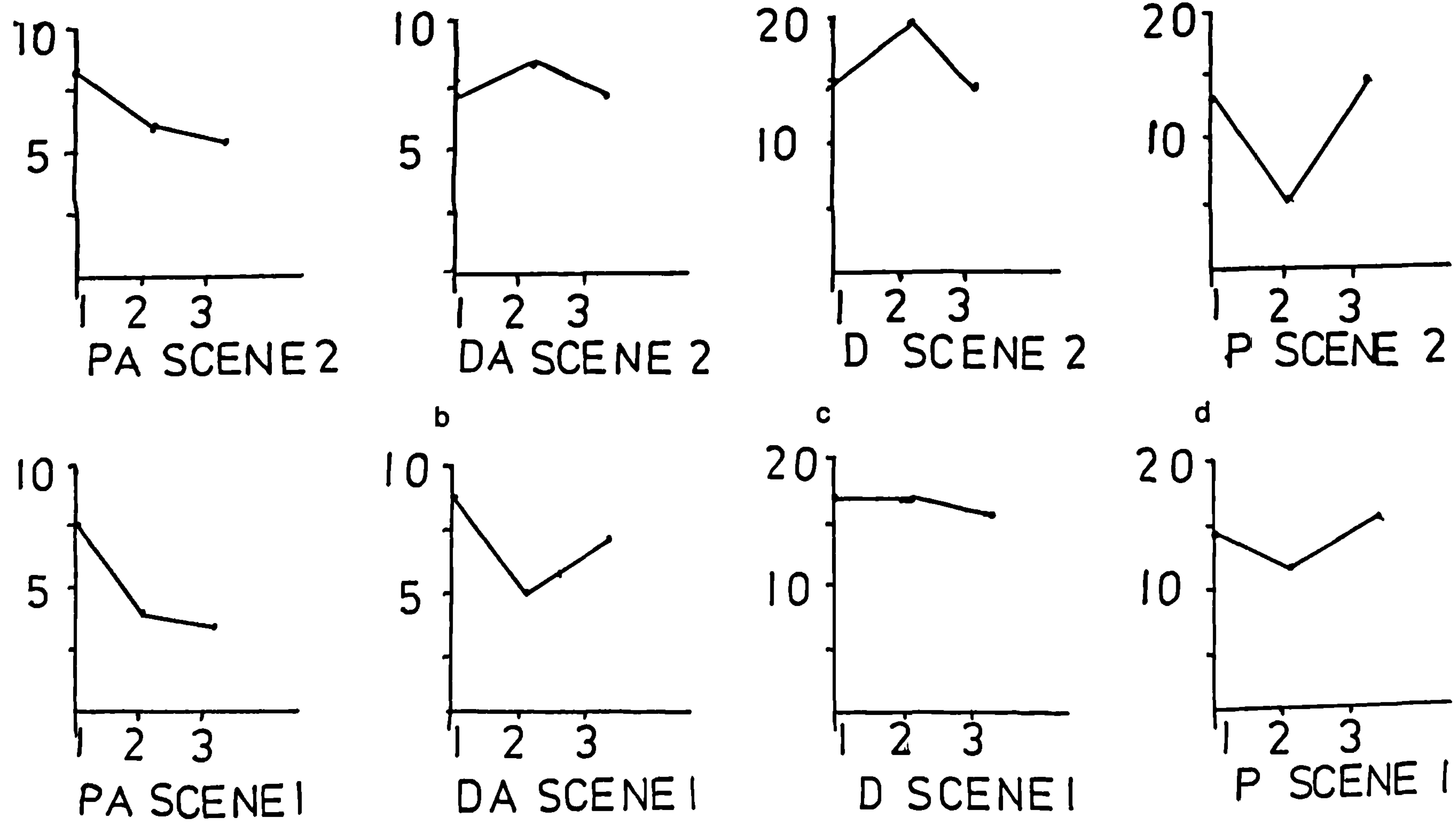
The task i operation

Scene 1 completed correctly



Scene 2

AVERAGE ERROR SCORES ALL OBSERVERS AGAINST NO. ATTEMPTS Fig 50



errors of confusion made by the colour defective observers to see if there was a consistent pattern between groups or types of defectives. The table below shows the most frequent colour confusions made by each group of colour defective observers.

Deuteranopes D	Deuteranomalous DA	Protanopes P	Protanomalous PA
Cyan/Magenta	Green/Yellow	Green/Yellow	Green/Yellow
Green/Yellow	Green/Red	Green/Red	Green/Red
Green/Red	Yellow/Red	Cyan/Magenta	Cyan/Blue
Blue/Magenta	Cyan/Magenta		Cyan/Magenta
Green/Magenta			Yellow/Red

Table 48 To show the colour confusions made by colour defectives at the photo-finishing task. In descending order of frequency.

There are no obvious distinguishing factors between the protan/deutan groups shown here*, confusions between red, yellow and green would be expected by both groups and occur frequently. The Cyan/Magenta confusions by deuteranopes

* partly because of the complex nature of the scene and the colour bias of the prints.

and to a lesser extent by the deuteranomalous, are also typical of the colour confusions of deutans.

	Observer No.	28/33	8	19	14	1	22	12	30	15	34	11	25	Total	Percent
		Code Number of Individual Prints													
DEUTERANOPES	D6	1.8	0.6	1.2	0	0.6	2.0	1.2	2.3	2.0	1.0	1.6	0.8	15.1	42.0
	D13	1.8	1.6	0.8	0	0.8	2.8	1.2	2.2	0.8	1.2	1.5	1.5	16.2	45.0
	D14	2.1	1.3	1.5	0.8	1.3	2.1	1.2	2.1	2.5	1.2	1.5	2.5	20.1	55.8
	D16	3.2	1.5	1.2	1.5	2.2	2.5	1.7	2.5	1.3	1.2	1.5	2.0	22.3	62.0
	D26	1.0	1.3	1.3	0	0.8	0.5	1.2	1.3	0.6	0.6	1.0	1.2	10.8	30.0
	D27	2.7	1.3	1.3	1.3	1.5	2.0	2.1	2.8	1.2	0.8	1.7	1.5	20.2	56.0
	D17	1.7	1.5	0.7	0	1.3	0.8	0.5	3.5	0	0.8	1.8	1.8	14.4	40.0
	D25	1.8	0.5	0.8	1.5	0.0	1.0	1.2	1.3	1.2	1.0	0.6	2.0	12.9	35.8
	D29	2.0	0.8	1.2	0.8	0.8	0.2	0.6	0	1.7	1.0	1.0	1.0	11.1	30.8
	Total	18.1	10.4	10.0	5.9	9.3	13.9	10.9	18.0	11.3	8.8	12.2	14.3	484.4	
	Average	2.0	1.2	1.1	0.65	1.0	1.5	1.2	2.0	1.25	1.0	1.35	1.6	AV	53.8%
DEUTERANOMALOUS	D71	0	0.1	0.1	0	0	0	0.1	0	0.6	0.3	0	0	1.2	3.3
	D43	0.5	0.25	1.75	1	1	1	1.25	0.25	0.5	0.75	1.25	0	9.5	26.4
	D53	1.25	0.75	1.0	1.0	0.75	0	0.25	0	0.75	1.25	0.75	1.25	9.0	25.0
	D54	0.5	1.0	0.5	0	0.75	0.75	1.25	1	0.75	1.5	0.75	0.75	9.5	26.4
	D51	0	0.5	0.5	0	0	0	0	0	0.25	0.25	0	0	1.5	4.2
	D61	1.5	0.8	0.8	1.3	1.0	0.2	0.7	1.3	0.2	0.6	1.2	0.6	10.2	28.3
	D68	0.2	0.3	0.5	0	0.3	0	0.2	0	0.3	0.8	0.2	0.3	3.1	8.6
	D57	1.0	1.5	0.5	1.5	1.0	0	0.5	0	2	1.0	1.0	0	10.0	27.7
	D42	0.3	0.8	0	0.5	0.5	0.1	0.8	0	0.3	0.8	0.8	0.5	5.4	15.0
	D59	1.5	0	1.0	0.5	0.2	0	0.3	0	0.5	0.3	0.3	0.5	5.1	14.2
	D49	1.0	1.0	1.0	0	0	0	0	0	0.5	0.5	0.5	0	4.5	12.5
	D58	0	0.8	0.5	0.5	0.5	0.5	0.5	0	0.3	0.5	0.66	0	4.76	13.2
	D45	3	0.5	1.0	3.0	1.5	2.0	1.5	0.5	0	0	2.0	0	15.0	41.7
	D46	1.6	1.6	1.0	1.0	0.6	2.0	1.0	3.3	0.6	0.6	0.4	3.0	16.7	46.4
	D44	1.8	1.2	1.0	0.5	1.3	1.3	1.5	1.0	1.0	1.0	1.2	1.8	14.6	40.6
	D33	0.8	1.2	1.0	0.6	0.6	0.3	0.5	0	1.3	0.5	0.5	1.5	8.8	24.4
	D67	0.2	0.5	0.5	0.5	0.2	0	0.8	0	0.5	0.6	0.3	0	12.9	35.8
	D55	0.2	0.2	0.3	0	0.3	0	0	0	0.5	0.3	0.2	0	2.0	5.6
	D49	0	0.2	0.2	0.3	0.6	0.2	0.2	0	0.7	0	0.5	0.5	3.4	9.4
	D52	1.2	1.2	1.2	0.6	0.8	1.0	0	0	1.2	0.6	0.8	0	8.6	23.9
	D50	0.8	1.3	1.2	0.5	1.2	0	0	0	0.5	1.2	0.6	0.8	8.1	22.5
	Total	17.35	15.7	15.55	13.3	13.1	9.36	11.35	7.35	12.71	13.35	13.9	11.5	455.1	
	Average	0.82	0.75	0.74	0.63	0.62	0.45	0.54	0.35	0.60	0.63	0.66	0.55	AV	21.7%

Table 46 Average score for eachprint (mean of three scores) and percentage errors for placement of prints by deutan observers.

	Observer No.	Code Number of Individual Prints 28/33	8	19	14	1	22	12	30	15	34	11	25	Total	Percent
PROTANOPES	P11	2.5	0	2	0	2	2.5	0	0	0	1	3.0	1.5	14.5	40.3
	P 2	1.0	1.3	0.8	1.0	1.3	1.3	1.2	0	0.8	0.8	0.5	2.0	12.0	33.3
	P13	1.3	0.5	1.5	1.5	1.0	2.0	1.8	0	1.3	1.0	1.2	2.3	15.4	42.7
	Total	4.8	1.8	2.5	2.5	4.3	5.8	3.0	0	2.1	3.8	4.7	5.8	116.3	
	Average	1.6	0.6	0.8	0.8	1.4	1.9	1.0	0	0.7	0.9	1.6	1.9	AV	38.8%
PROTANOMALOUS	P19	0.5	0.5	0.5	0.8	0.8	0.5	1.0	0.25	0.25	0.5	0.5	0.5	6.6	18.3
	P18	0	0	0	0	0	0	0	0	0	0	0	0	0	
	P17	0.2	0.2	0.2	0.5	0.2	0.2	0	0	0.2	0.2	0	0	1.9	5.3
	P20	1.8	0.5	1.3	2.0	1.3	1.5	1.3	0.3	2.2	1.0	2.0	2.8	18	50.0
	P22	0.8	0	0.3	0.5	0	0	0	0	0.2	0.2	0	0	2.0	5.6
	P21	1.8	0.8	0.8	0.6	1.2	0.6	0.6	0	0.7	0.8	1.5	1.2	10.6	29.4
	P25	1.0	2.0	1.0	1.0	1.0	0	0.5	3.0	3.0	0.5	0.5	1.0	14.5	40.3
	Total	6.1	4.0	4.1	5.4	4.5	2.8	3.4	3.55	6.55	3.2	2.5	5.5	148.9	
	Average	0.87	0.57	0.59	0.77	0.64	0.4	0.48	0.51	0.94	0.46	0.36	0.75	AV	24.8%

Table 47 Average score for each print (mean of three scores) and percentage errors for placement of prints by protan observers.

Colorimetric measurement of prints

An attempt was made to obtain colorimetric measurement of the prints used in the trial. This was not an easy task because the scenes were complex and it was not possible to integrate the whole print colour bias.

At the recommendation of Kodak Research Laboratories[1] measurements were made with the Lovibond flexible optic Tintometer subtractive colorimeter. An area of scene was chosen which was as uniform as possible - the far right edge of the sea scene - and visual matches were made of this area on most prints, using the Tintometer colorimeter. The results are shown in table 49 together with the C.I.E. x,y and u',v' chromaticity co-ordinates obtained from conversion graphs. Each measurement shown in the table 49 is the mean of two independent readings taken on consecutive days. Where the results differ considerably the two independent readings are presented. The C.I.E. x,y and u',v' chromaticity co-ordinates are plotted in figures 45 and 46 , and graphs showing the chromaticities of certain sections of the photofinishing chart are shown in figures 47 to 49 .

The results are irregular, but discussions with Kodak[1] revealed similar results have been produced in that/their experience. The main sources of errors as given

1. Dr. R. Hunt, Kodak Ltd.

below are thought to account for the irregularity:

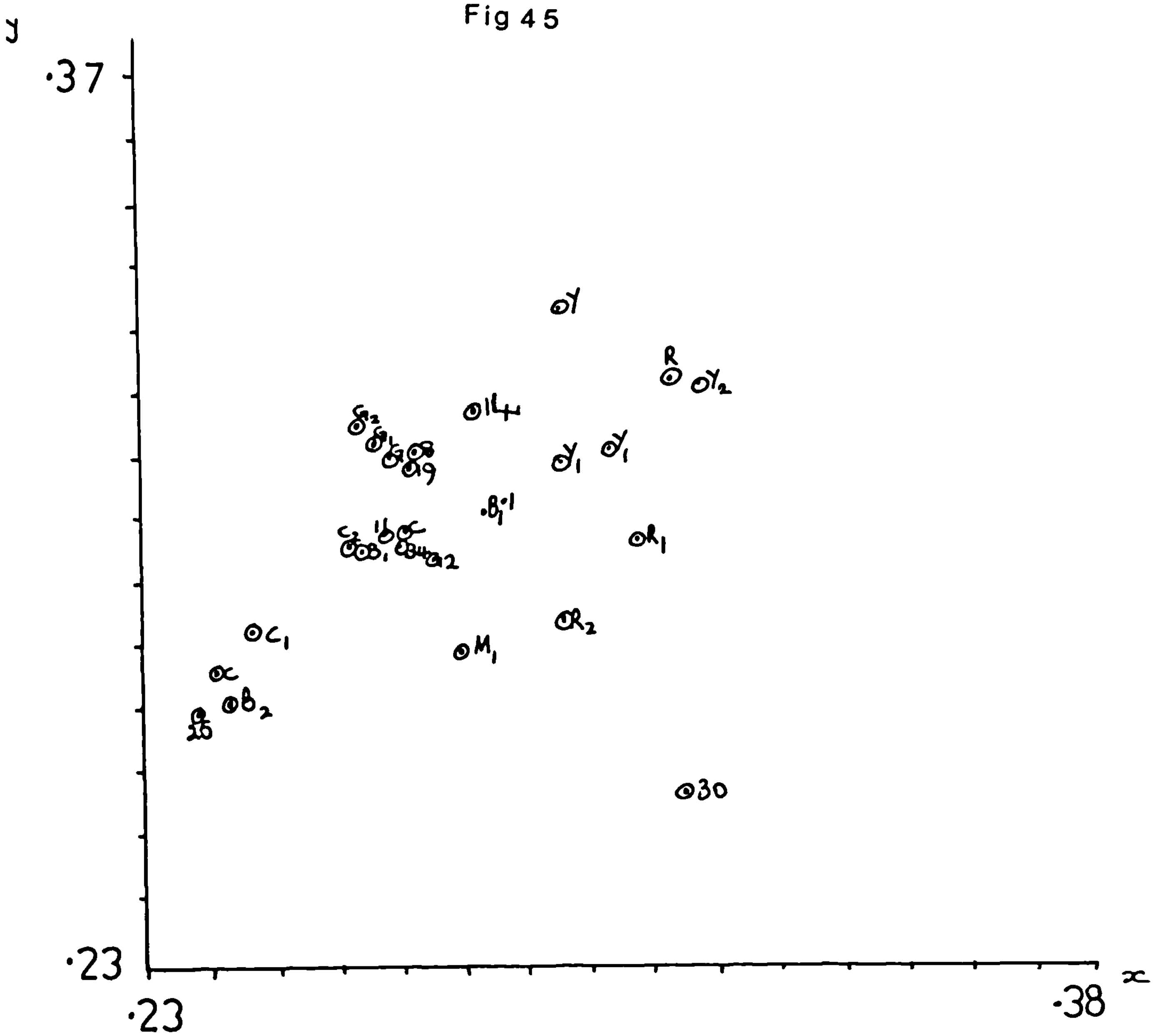
1. Difficulty of accurate colorimetry of complex scenes in reflection prints.

2. Use of visual colorimeters.

3. Small differences in density throughout the prints.

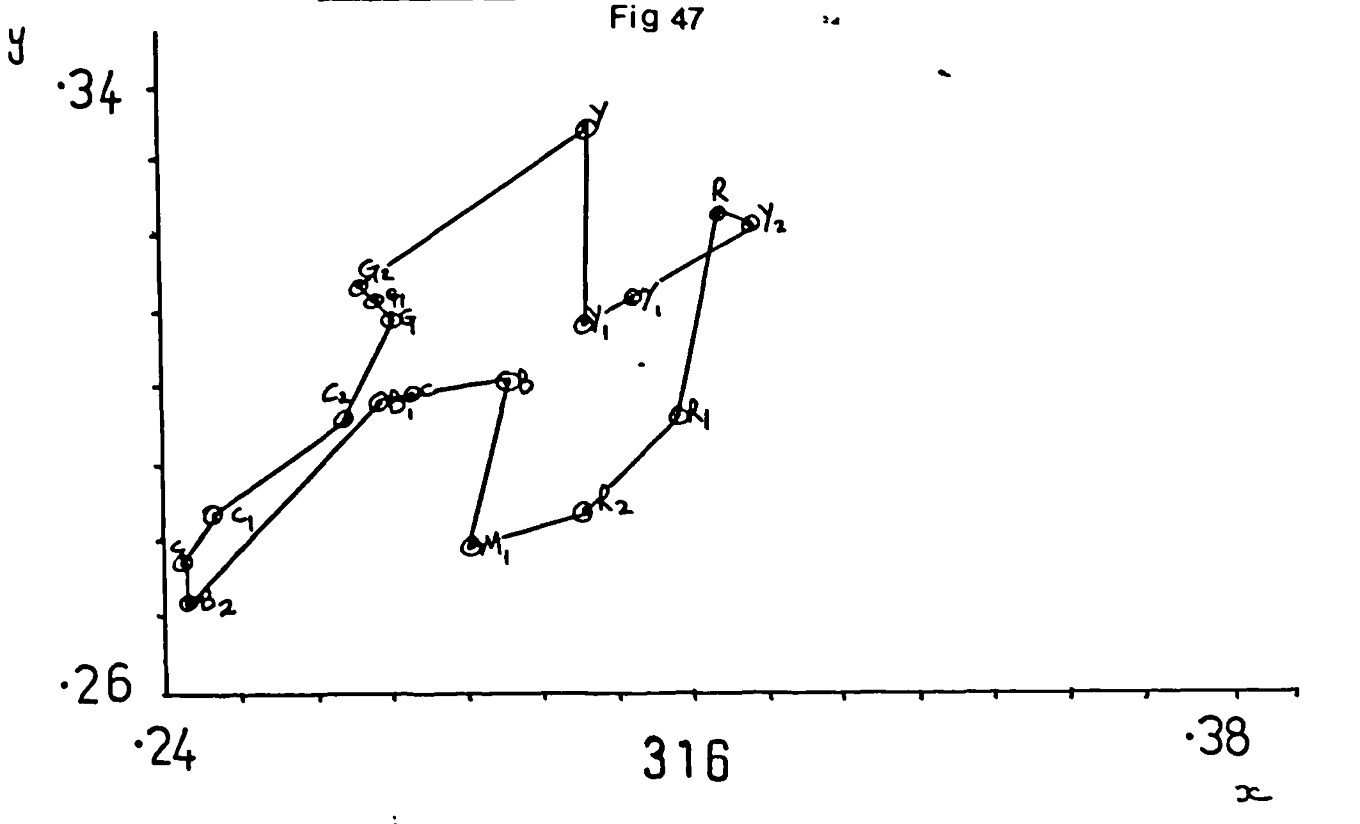
CHROMATICITY CO-ORDINATES (x,y) OF COLOUR PRINTS USED IN PHOTO-FINISHING TRIAL

Fig 45



FIXED PRINTS REPRESENTING MAXIMUM COLOUR SHIFTS

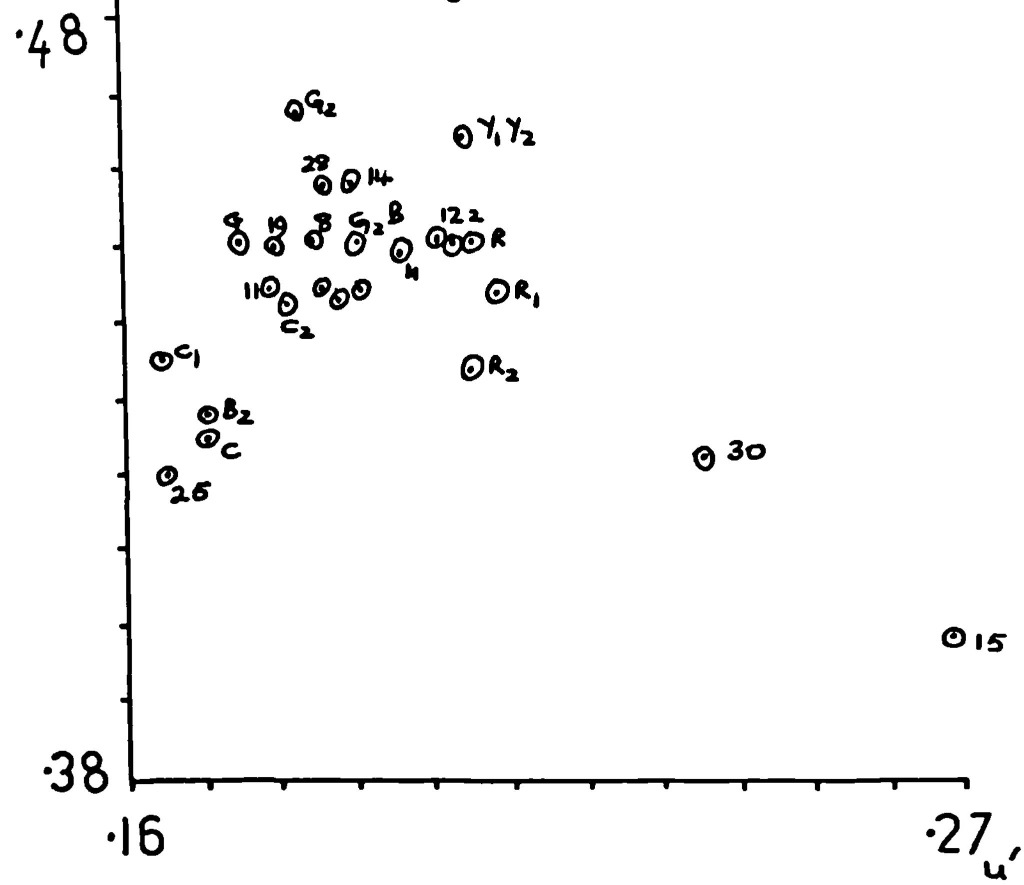
Fig 47



CHROMATICITY CO-ORDINATES (u′v′) OF COLOUR PRINTS

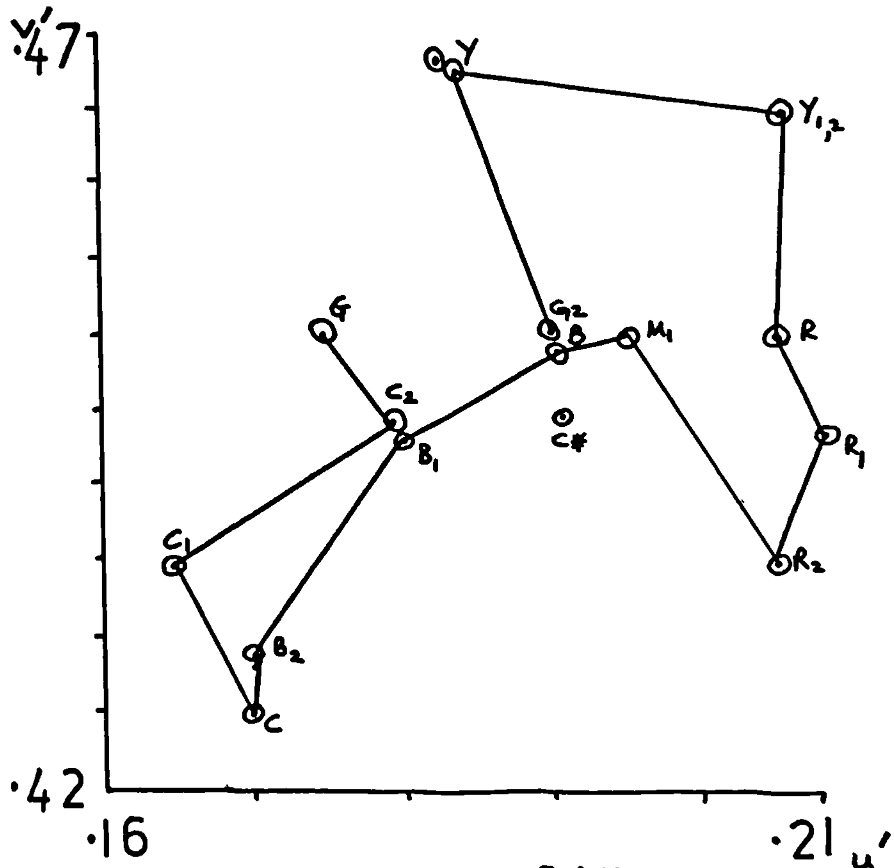
USED IN PHOTOFINISHING TRIAL

Fig 46



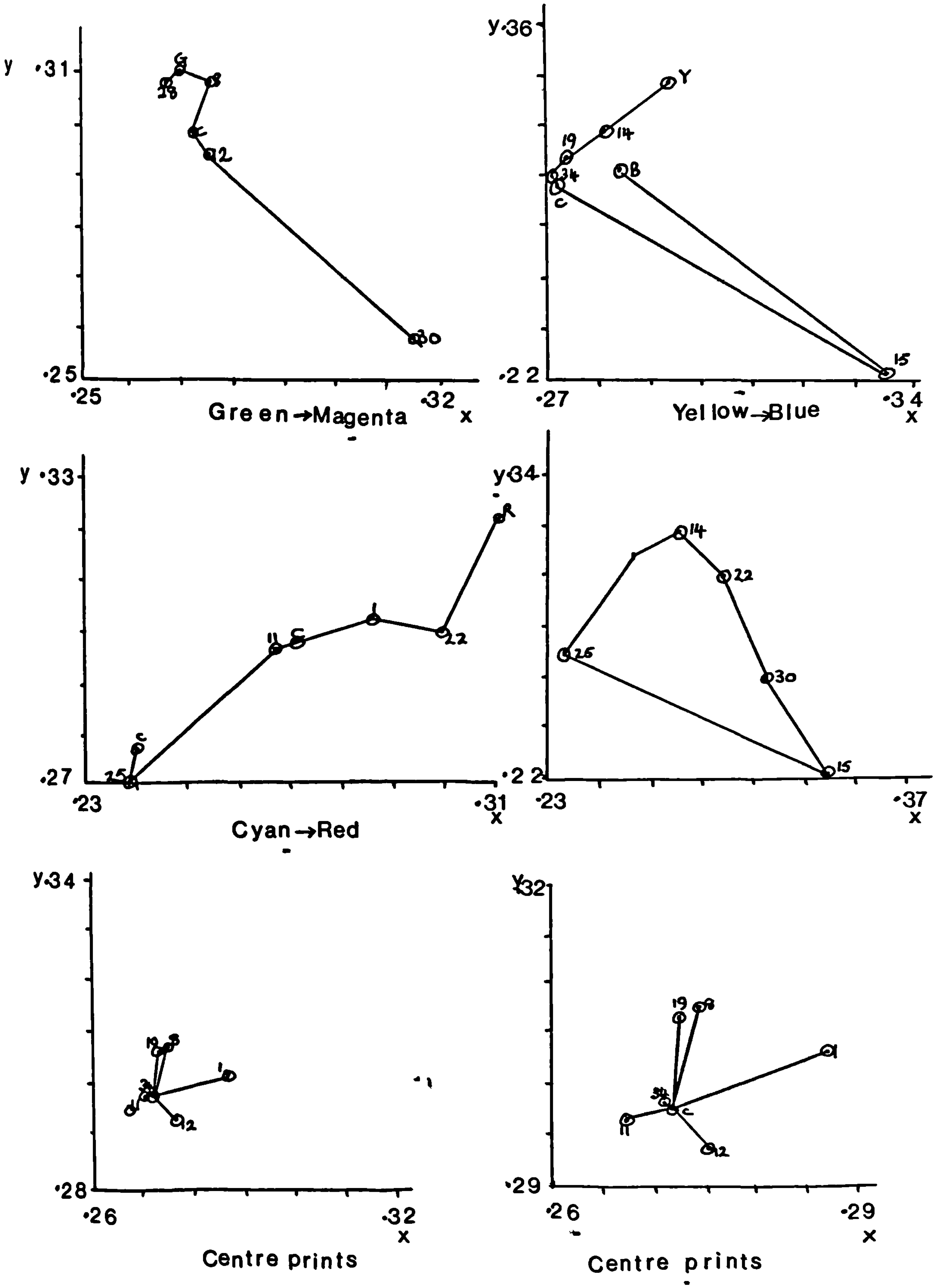
FIXED PRINTS REPRESENTING MAXIMUM COLOUR SHIFTS

Fig 48



CHROMATICITY CO-ORDINATES (x.y) OF COLOUR PRINTS FORMING COLOUR SEQUENCES

Fig 49



Print No.	Lovibond Tintometer Units			C.I.E. co-ordinates			
	B	Y	R	x	y	u	v
Centre	3.1	1.2		0.272	0.298	0.19	0.443
G	4.0	2.0		0.270	0.310	0.175	0.450
G_1	4.3	2.3		0.268	0.312	0.172	0.453
G_2	3.8	2.0		0.265	0.315	0.190	0.450
Y	2.5	1.8		0.295	0.335	0.183	0.468
Y	2.1	1.5		0.296	0.324	0.182	0.465
Y_1	1.5	0.9		0.303	0.312	0.202	0.462
Y_1	1.4	0.6		0.295	0.310	0.205	0.465
Y_2		0.3	0.2	0.317	0.323	0.205	0.465
R	0.1		0.6	0.312	0.323	0.205	0.450
R_1	0.5		0.6	0.307	0.298	0.208	0.443
R_2	1.1		0.7	0.295	0.285	0.205	0.435
M_1	1.9		0.3	0.280	0.280	0.195	0.450
B	2.1	0.7		0.284	0.301	0.190	0.450
B_1	3.9	1.3		0.264	0.294	0.180	0.443
B_2	5.8	1.9		0.243	0.272	0.170	0.428
C	5.9	2.0		0.241	0.277	0.170	0.425
C_1	5.6	2.2		0.246	0.284	0.165	0.435
C_2	4.4	1.9		0.246	0.296	0.180	0.443
28	4.1	1.9		0.267	0.308	0.175	0.450
28	3.5	1.6		0.273	0.317	0.187	0.458
8	3.1	1.4		0.275	0.308	0.185	0.450
19	3.5	1.6		0.273	0.307	0.180	0.450
14	3.1	1.8		0.282	0.318	0.190	0.458
1	2.0	0.7		0.287	0.303	0.200	0.450
22	0.6		0.1	0.300	0.300	0.202	0.450
12	2.5	0.6		0.276	0.294	0.185	0.443
30	1.5	0.0		0.315	0.258	0.235	0.423
34	3.2	1.2		0.272	0.298	0.184	0.443
15	3.9	1.4		0.335	0.220	0.268	0.398
11	3.7	1.5		0.268	0.297	0.178	0.443
25	5.7	2.0		0.238	0.270	0.165	0.420

Table 49 Colorimetric value of prints

Mean of two independent measurements using Lovibond flexible fibre-optic Tintometer colorimeter.

PRI! TING RIAL

Name   Date

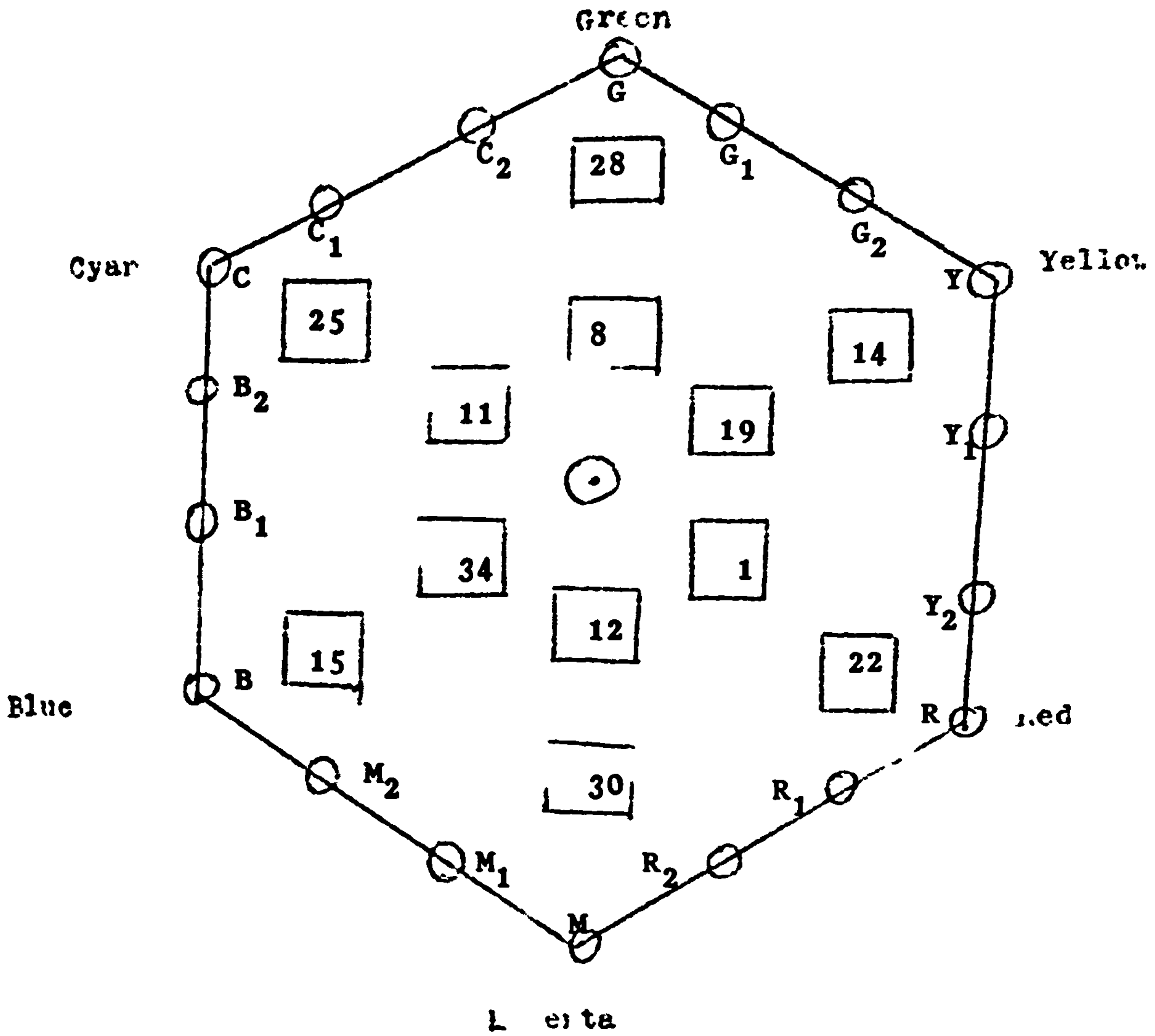


Table 50 To show positions and identification of prints

J.Voke 6/3/73

DEPARTMENT OF OPHTHALMIC OPTICS
AND VISUAL SCIENCE
THE CITY UNIVERSITY
CRANWOOD STREET LONDON E.C.1

Performance of Colour Normals

Nine colournormal observers carried out scene one task and seven colour normals took part in scene two task. In most cases the observers for scenes one and two were identical i.e. observers were asked to perform both tasks.

Colour defective observers mostly performed each task three times to see if there was any variability in performances and any possible learning effect. This was felt to be desirable because anomalous trichromats often give variable responses. All colour normals, except one, performed each task only once. The results are presented in Table 52 .

TABLE 52
Results - colour normals

Scene 1 errors	Scene 2 errors
0	0
0	0
0	0
6	2
6	6
2	6
4	2
2	
4	
Average 2.6	Average 2.2

Total average of scene one and two = 2.5 errors.

Percentage error $= \frac{2.5}{36} \times 100 = 6.9\%$

One observer performed the scene one five times to see if there was any effect of learning. His error scores were 7,6,6,2,0. This does show a possible learning effect although it is not reasonable to draw any firm conclusions from the results of one observer. It is known that considerable improvement in performance occurs in industrial colour situations by colour normals, through learning.[1]

Possible learning effects by colour defective observers

The figures 50a to 50d indicate the effect that learning and familarity has on the performance of a selection of colour defective observers at the photo-finishing task. The average error scores for all colour defective observers within their different groups are shown in fig. 51. It is evident that no overall learning pattern emerges, although a slight reduction in errors occurs for the protanomalous and deuteranopic observers.

1. Private communication by Dr. R. Hunt, Kodak Ltd.

Conclusions

It will be noted from Tables 51 and and figures 51 and 52 that the major errors are made by deuteranopic observers (53.8% errors) and protanopic observers (38.8% errors). Errors made by anomalous trichromats are considerably fewer and there is greater similarity between the deuteranomalous observers (21.7% errors) and protanomalous observers (24.8% errors) than the protanopes and deuteranopes. Untrained colour normal observers produce good results, making only 6.9% errors. Learning and experience may improve their score further.

Dichromatic observers therefore show the greatest handicap in work of this nature. Their errors are considerable and could involve incorrect colour judgement in up to fifty percent of situations. The exclusion of dichromats from work of this nature is therefore essential.

Anomalous trichromats, though able to perform better than the dichromats, are still likely to make an error of judgement in twentyfive percent of cases. They also constitute a significant industrial hazard to the printing and photographic industries.

On the basis of this study recommendations can be made to restrict employment in colour jobs to observers with normal colour vision.

The incidence of the different types of defects must be borne in mind, however, and the figure 52 attempts to portray the extent of the overall position.

COLOUR VISION DEFECT	ERRORS %
D	53.8
DA	21.7
P	38.8
PA	24.8

TABLE 51 ERRORS MADE BY COLOUR DEFECTIVES AT PHOTOFINISHING TRIAL

FIGURE 51
ERRORS MADE AT
PHOTOFINISHING TRIAL

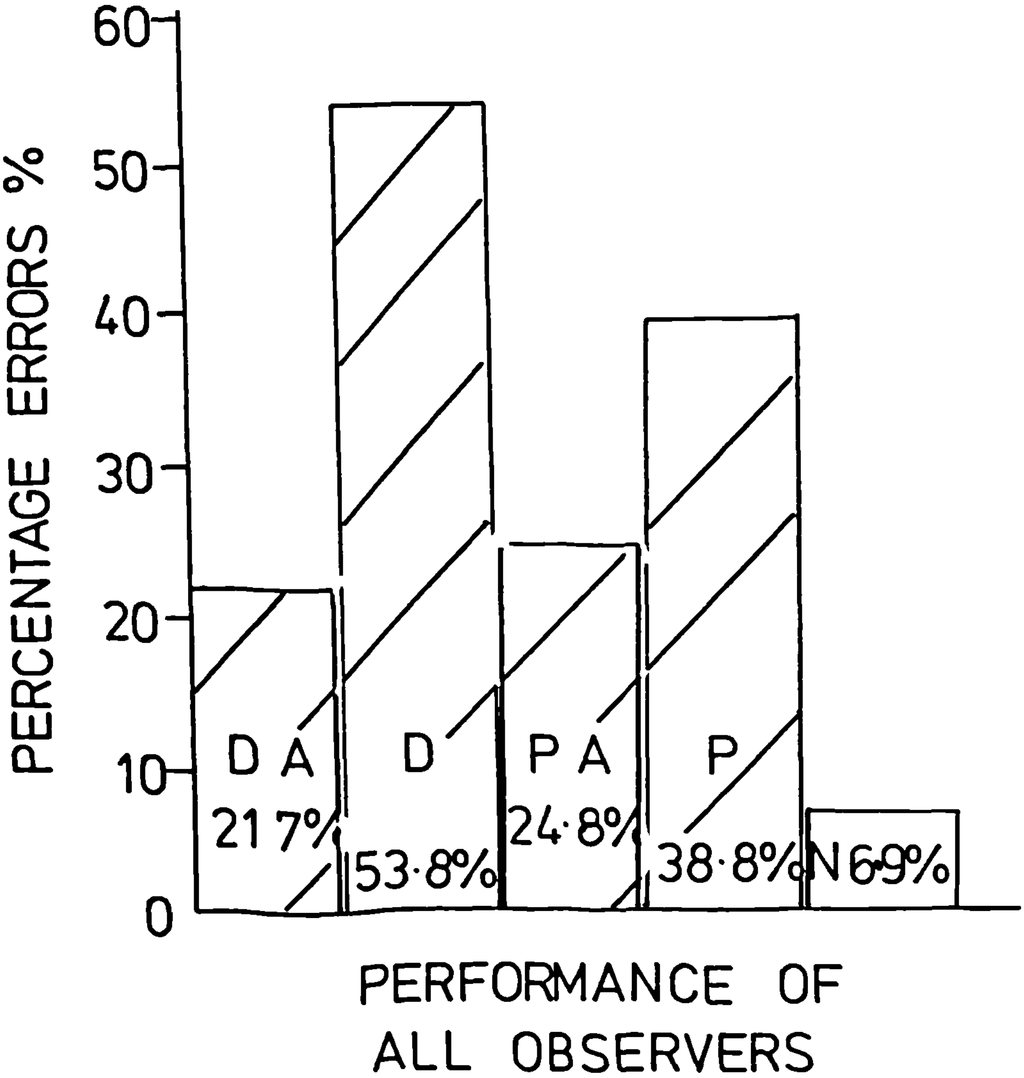
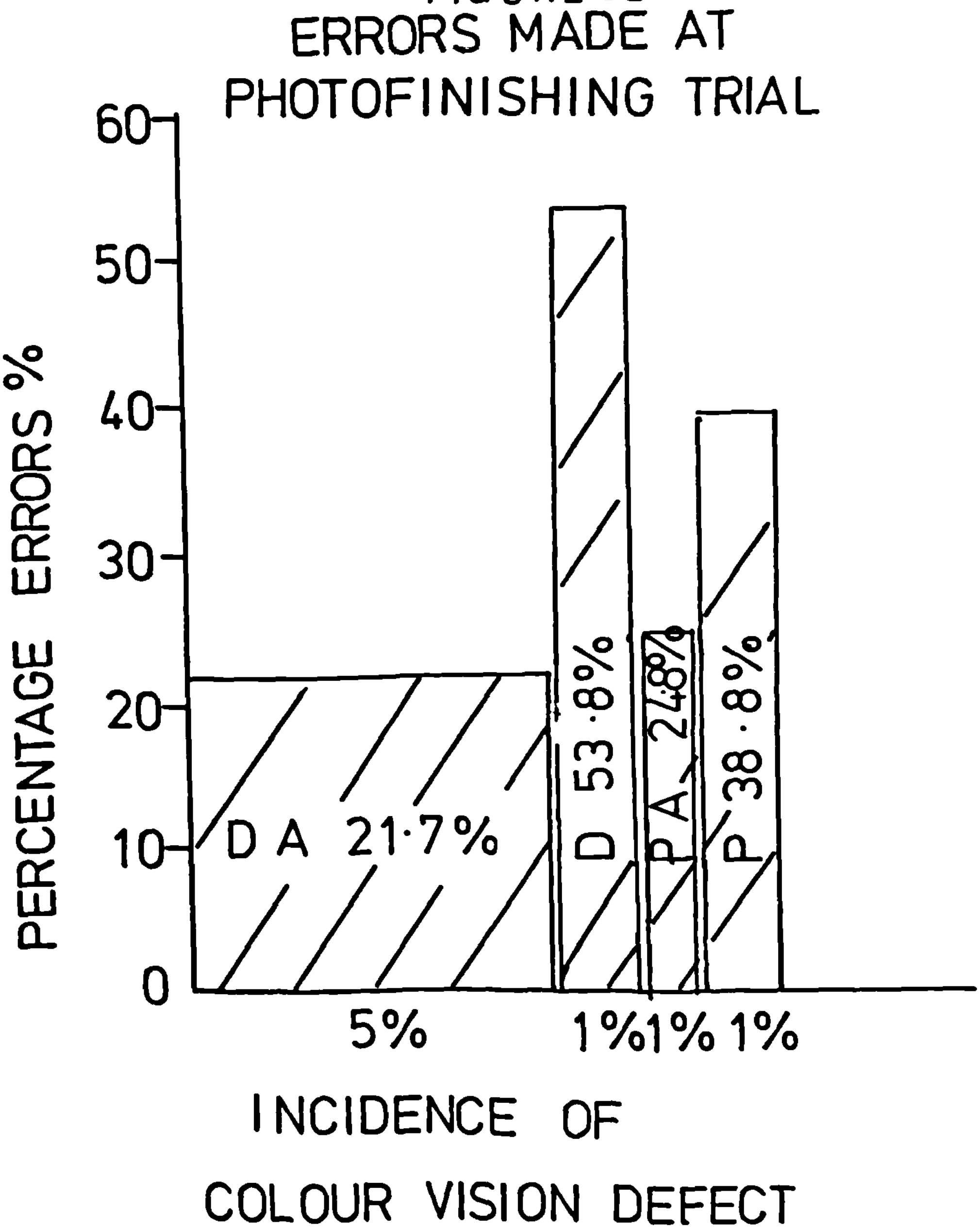


FIGURE 52


ERRORS MADE AT
PHOTOFINISHING TRIAL
PERCENTAGE ERRORS %
60
50
40
30
20
10
0
D A 21·7%
D 53·8%
P A 24·8%
P 38·8%
5%
1%
1%
1%
INCIDENCE OF
COLOUR VISION DEFECT

DISCUSSION OF RESULTS

Errors made at Photofinishing Trial and colour vision test score

The errors made by colour defective observers for the two photofinishing tasks, together with the errors scored at standard colour vision tests are given in Table 53 . The data is presented in graphical form in figures 53 to 64 . As with the electrical trial such a comparison is useful because it indicates how suitable clinical colour vision tests are for predicting practical abilities at industrial colour work.

Two of the three methods of analysis used for the electrical trial were applied to the data obtained in the photofinishing trial - namely the coefficient of correlation and the summation of deviations from the lines of best fit for five colour vision tests used.

The results are given in Table 54 and 55 . A low coefficient of correlation was obtained for all data except for the D.15 test.

The ratings for the colour vision tests used and the deviations from the line of best fit for the data are given below in descending order of merit:

TABLE 53
PHOTO-FINISHING TRIAL RESULTS

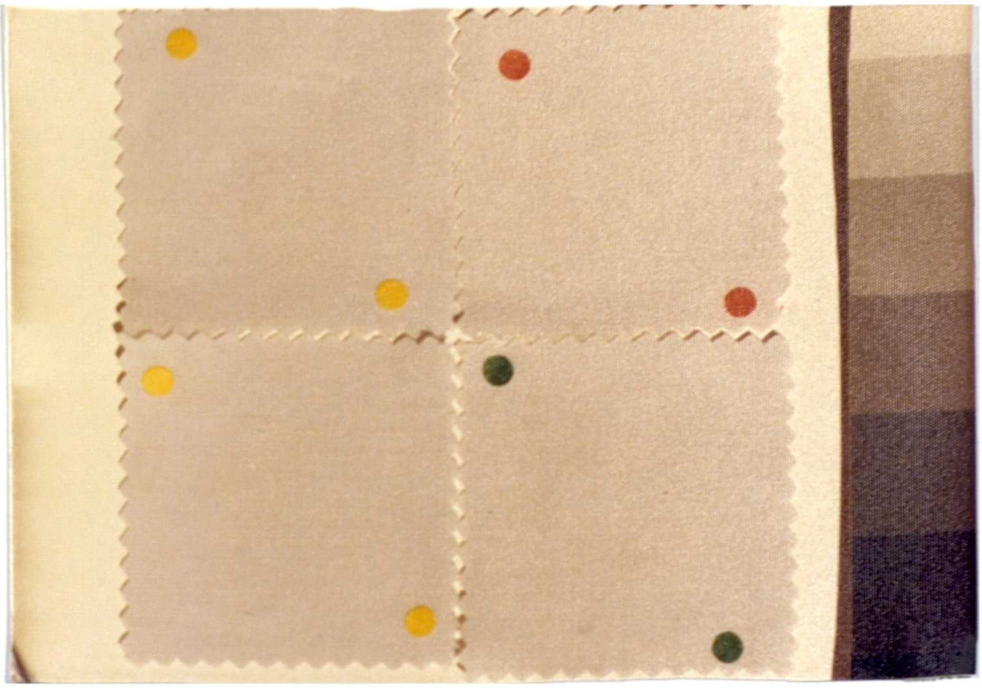
Protan and Deutan Observers

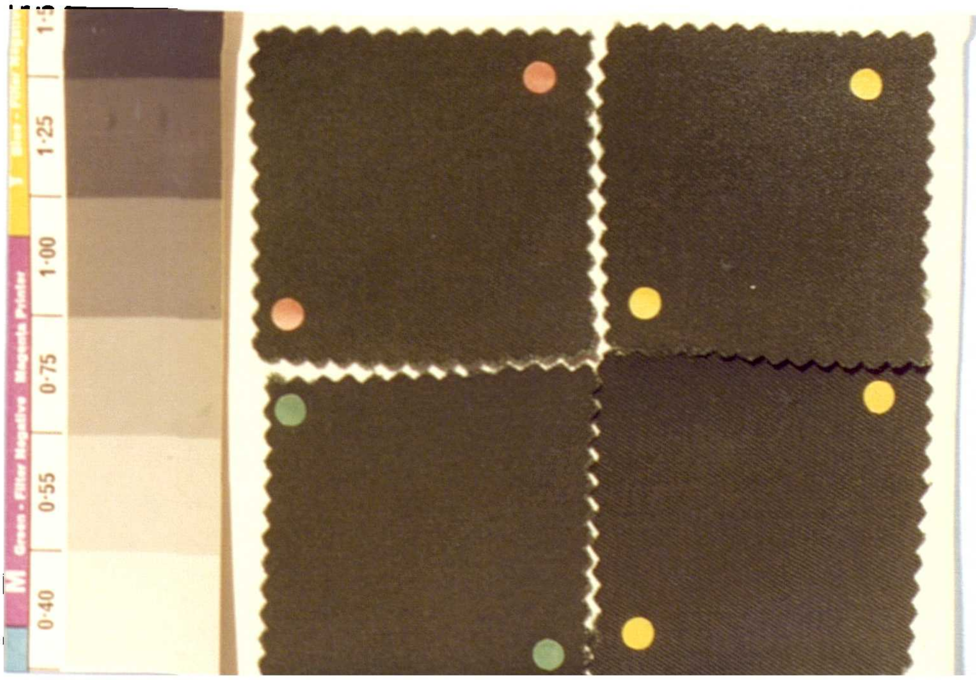
Number	Scene 1			Scene 2			Average Scene 1	Average Scene 2	100 Hue Score	Ishihara Errors	HRR Errors	Lovibond CVA Range	Nagel Range	Nagel Midpoint	D15 Cross
	1	2	3	1	2	3									
P 2	12	12	16	12	6	16	13	11	189	20	12	140	75		12
P11	15			17					70	20	6	140	75		10
P17	10	0	3	0	0	0	5	0	32	20	12	45	65	32	None
P19	6	0		16	8		3	12	149	20	14	135	20	50	None
P25	12			18					66	16	4		3	62	1
P22	6	0	0	0	0	2	2	0	56	19	14	25	15	57	None
P21	12	7	8	13	14	10	10	13	107	9	11	40	16	56	2
P20	8	15	19	20	22	20	14	21	121	20	11	50	18	53	2
P18	2	0	0	0	0	0	1	0	46	7	3	30	28	54	1
P12	14	14	6	17	20	16	11	18	187	20		140			11
D 6	15	16	14	15	14	15	15	14	182	20	12	140	75		14
D13	21	14	18	9	18	16	18	14	161	20		70	75		10
D14	22	16	21	17	26	18	19	20	55	20	14	140	75		10
D16	22	23	19	22	20	20	21	21	219	20	12	140	75		12
D26	14	4	8	4	19	14	9	12	76	20	10	115	75		8
D27	23	25	13	23	19	18	20	20	416	17	14	140	75		12
D17	10	6	14	18	18	20	10	18	343	20	11		75		11
D25	12	14		23	23		13	23		20	9	95	75		12
D29	6	12	12	6	18	14	10	13		20		140	75		8
D57	6			14					83	20	11	70	15	17	None
D42	2	8	2	6	7	6	4	6	204	20	6	140	38	19	2
D41	18								173	20	8	25	40	20	7
D59	6	0	4	4	0		3	2	54	20	9	77	14	17	None
D49	4			4					103	8	2	60	20	17	None
D58	8	6	0	2	6	6	5	5	83	20	6	60	15	17	2
D45	14			14						20	10		35	29	7
D46	18	22	25	14	20	20	22	18	191	20	12	90	35	17	9
D71	2	0	2	2	0	0	1	1	38	10	1	25	3	21	None
D43	8	8		12	10		8	11	272	20	6	50	36	18	4
D53	8	3		7	16		5	12	46	20	6		19	23	None
D54	10	8		10	10		9	10	108	20	8	65	18	16	None
D51	2	2		2	0		2	1	25		2	135	19	15	None
D61	6	13	12	4	13	10	10	9	179	20	5	35	12	11	9
D68	2	8	0	8	4	0	3	4	86	16	6	20	5	24	None
D44	10	14	18	14	20	12	14	15	93	20	11	55	35	17	None
D33	11	2	7	8	8	13	7	10	138	20	12	55	45	23	5
D67	6	4	9	2	6	2	6	3	28	5	None	50	5	17	None
D55	2	6	0	0	2	2	3	2	84	11	3	20	18	14	None
D49	0	0	4	4	10	2	3	5	103	8	2	60	20	17	None
D52	10	9	6	12	10	4	8	9	174	15	2	50	19	20	None
D50	13	8	6	10	6	6	9	7	100	20	8	55	20	22	None

Photofinishing Trial (average results)	H.R.R. Test D.15 Test Ishihara Test 100 Hue Test C.V.A. Test

Altogether the limitations of these methods of analysis mentioned in the Electrical Trial also apply to this trial, it does appear from these results that the D.15 test gives the best correlation for performance at a practical task of this nature, and on this basis recommendations can bemade to industries involved in colour printing to use the D.15 test as the best guide of potential performance.

Textile Trial





Key: yellow spots = standard sample
green spots = acceptable commercial match
red spots = unacceptable commercial match

Task and Test	Coefficient correlation	Gradient	Intercept on y axis
Trial 1 + 100 Hue	0.497	0.035	4.68
Trial 2 + 100 Hue	0.526	0.040	5.289
Trial 1 + HRR	0.511	0.732	3.225
Trial 2 + HRR	0.550	0.854	2.667
Trial 1 + Ishihara	0.432	0.561	-0.252
Trial 2 + Ishihara	0.483	0.705	-1.379
Trial 1 + CVA	0.407	0.057	4.835
Trial 2 + CVA	0.531	0.0842	3.311
Trial 1 + D15	0.750	0.917	5.306
Trial 2 + D15	0.675	0.934	6.580

Table 54 Analysis of Photofinishing Trial results.

Task and Test	Sum of distances from line of best fit.
Scene 1 + 100 Hue test	136
Scene 2 + 100 Hue test	175
Average for 100 Hue test	156
Scene 1 + HRR Test	139
Scene 2 + HRR Test	93
Average for HRR Test	116
Scene 1 + Ishihara test	148
Scene 2 + Ishihara test	139
Average for Ishihara test	144
Scene 1 + CVA test	141
Scene 2 + CVA test	182
Average for CVA test	161
Scene 1 + D15 test	121
Scene 2 + D15 test	150
Average for D15 test	135

Table 55 Deviations from line of best fit for photofinishing trial and results

FIG 53

PHOTOFINISHING TRIAL SCENE 1 AGAINST 100 HUE TEST SCORE

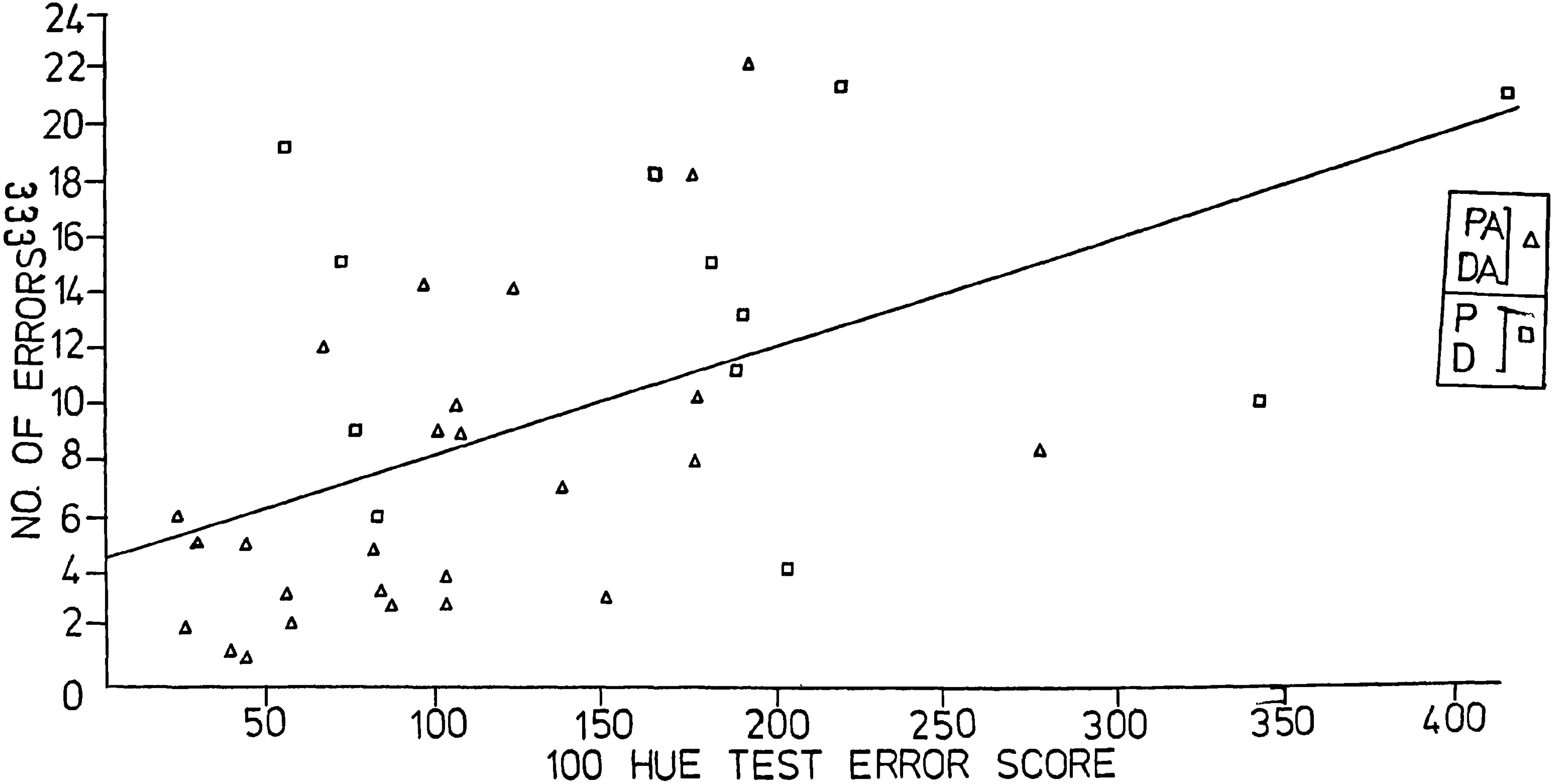


FIG 54

PHOTOFINISHING TRIAL SCENE 2 AGAINST 100 HUE TEST SCORE

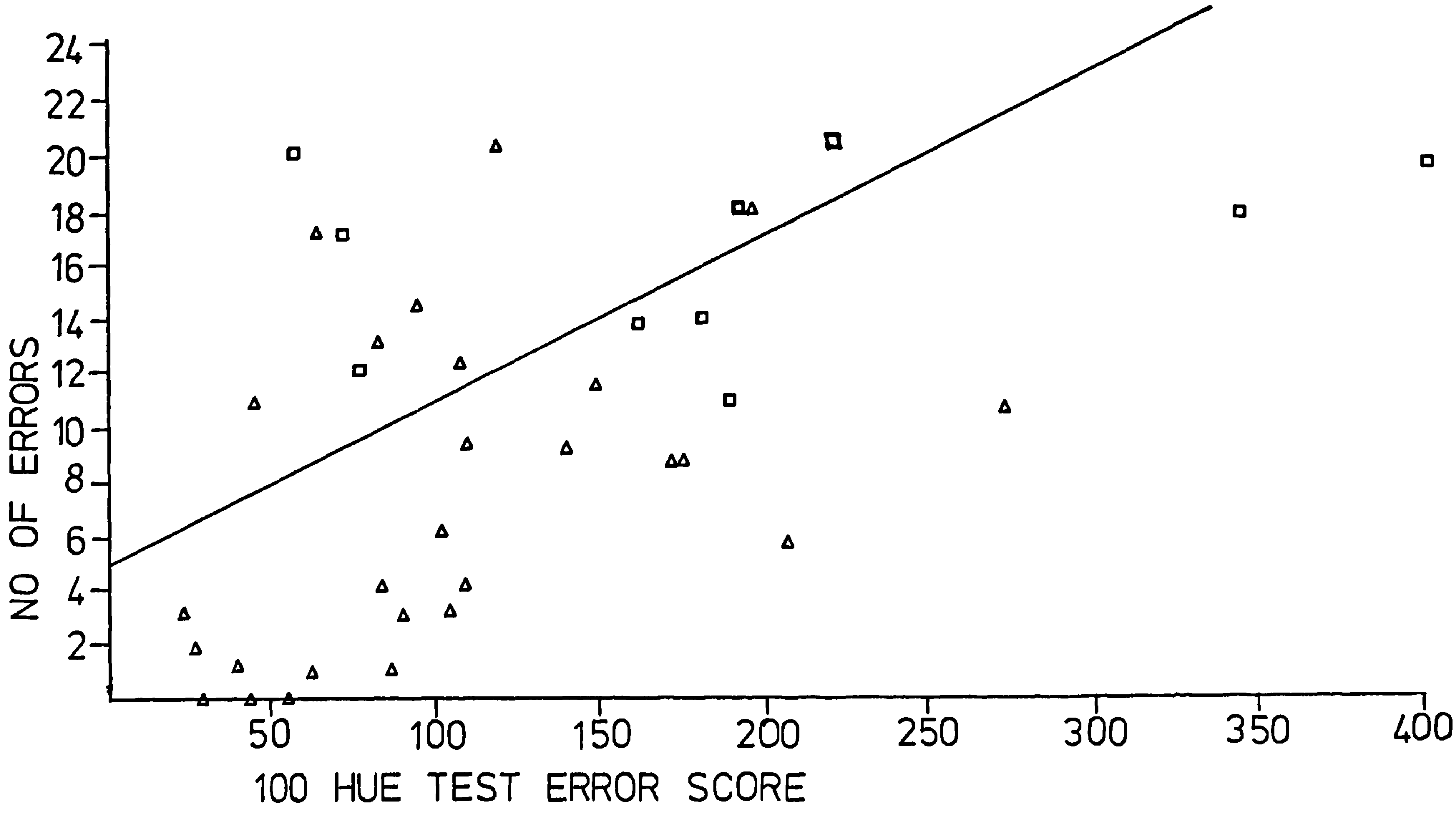


FIG 55
PHOTOFINISHING TRIAL SCENE 1 AGAINST LOVIBOND RANGE

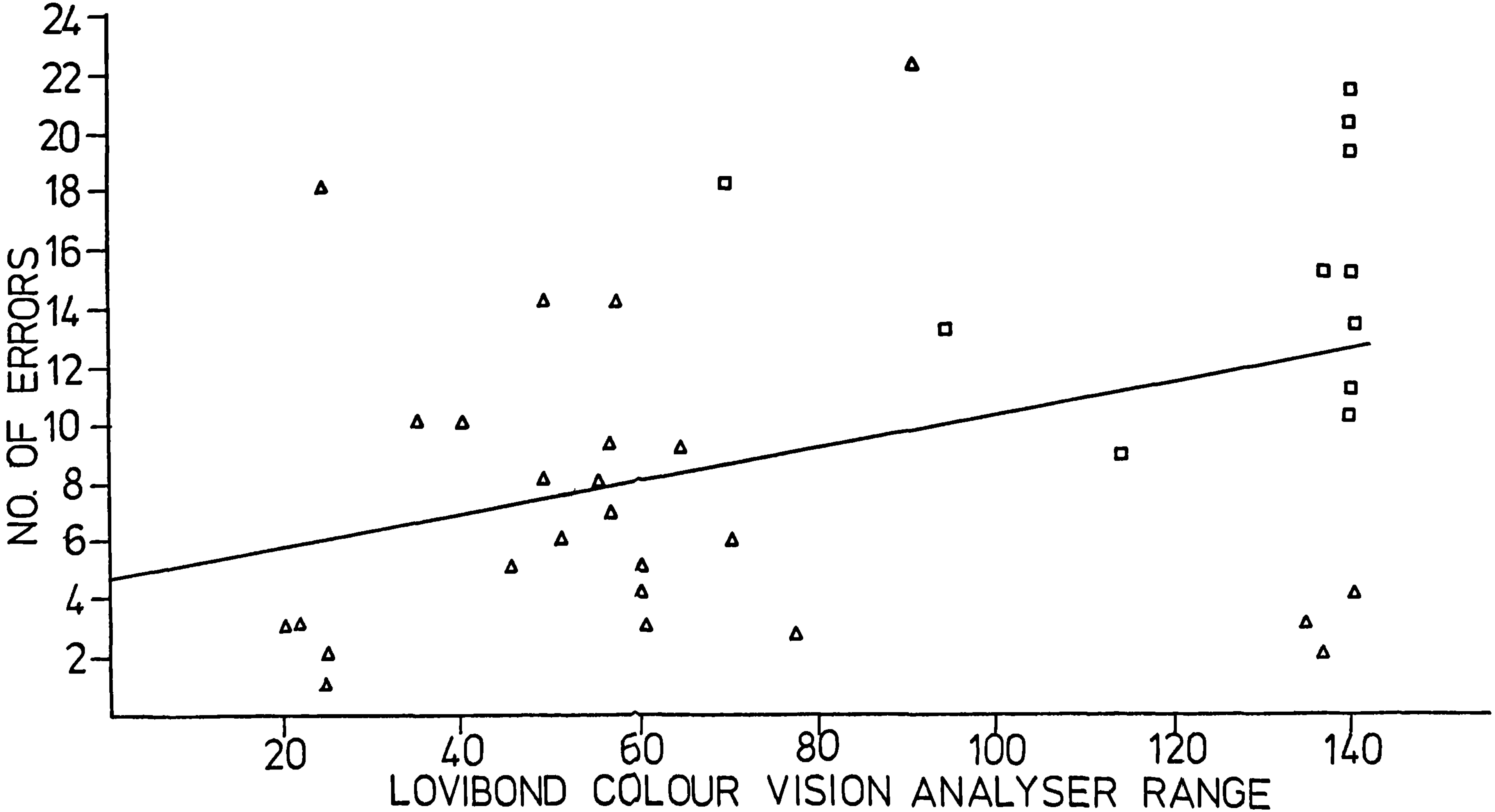


FIG 56
PHOTOFINISHING TRIAL SCENE 2 AGAINST LOVIBOND RANGE

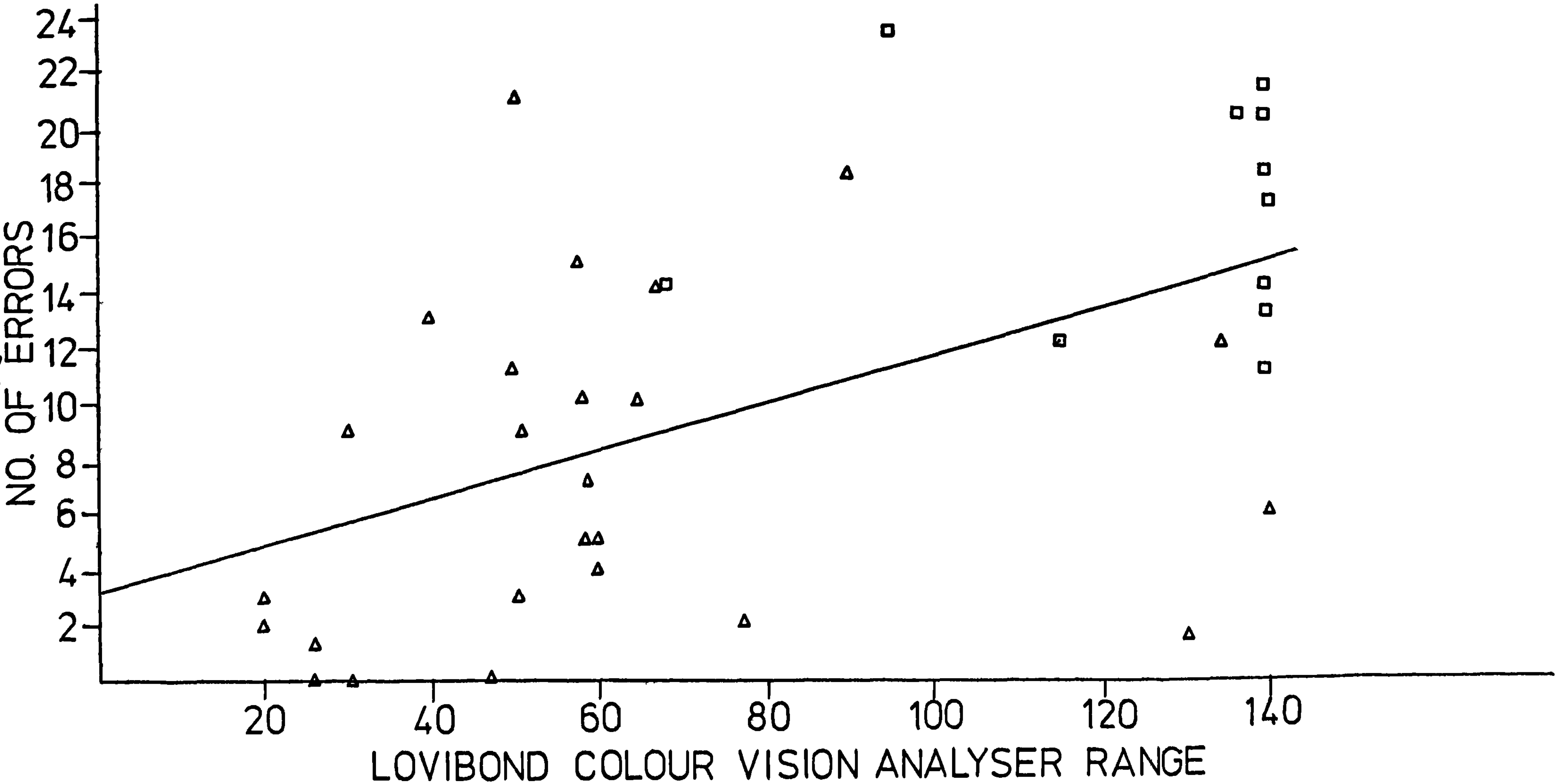


FIG 57
PHOTOFINISHING TRIAL ERRORS
AGAINST D 15 CONFUSIONS

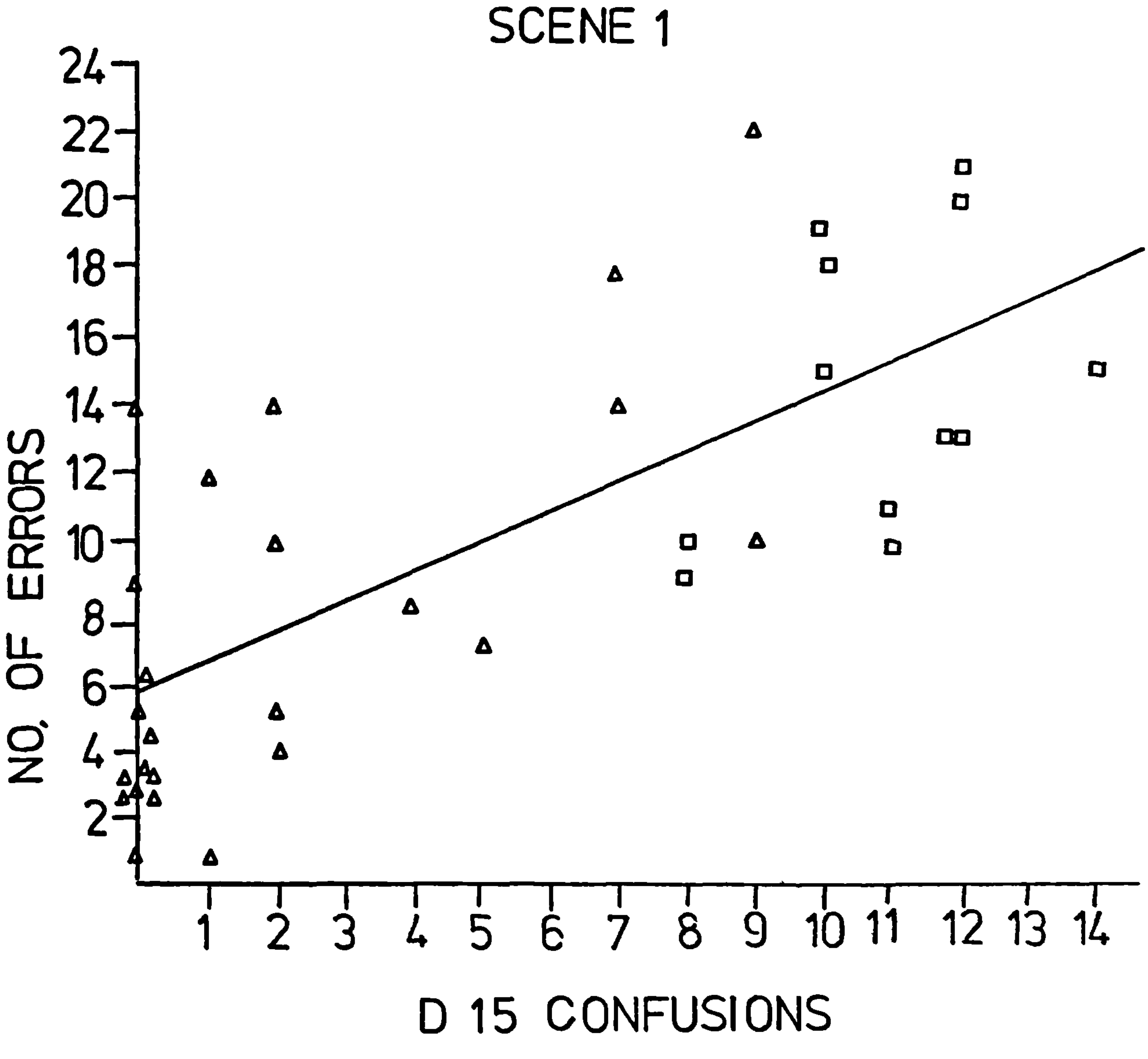


FIG 58
SCENE 2

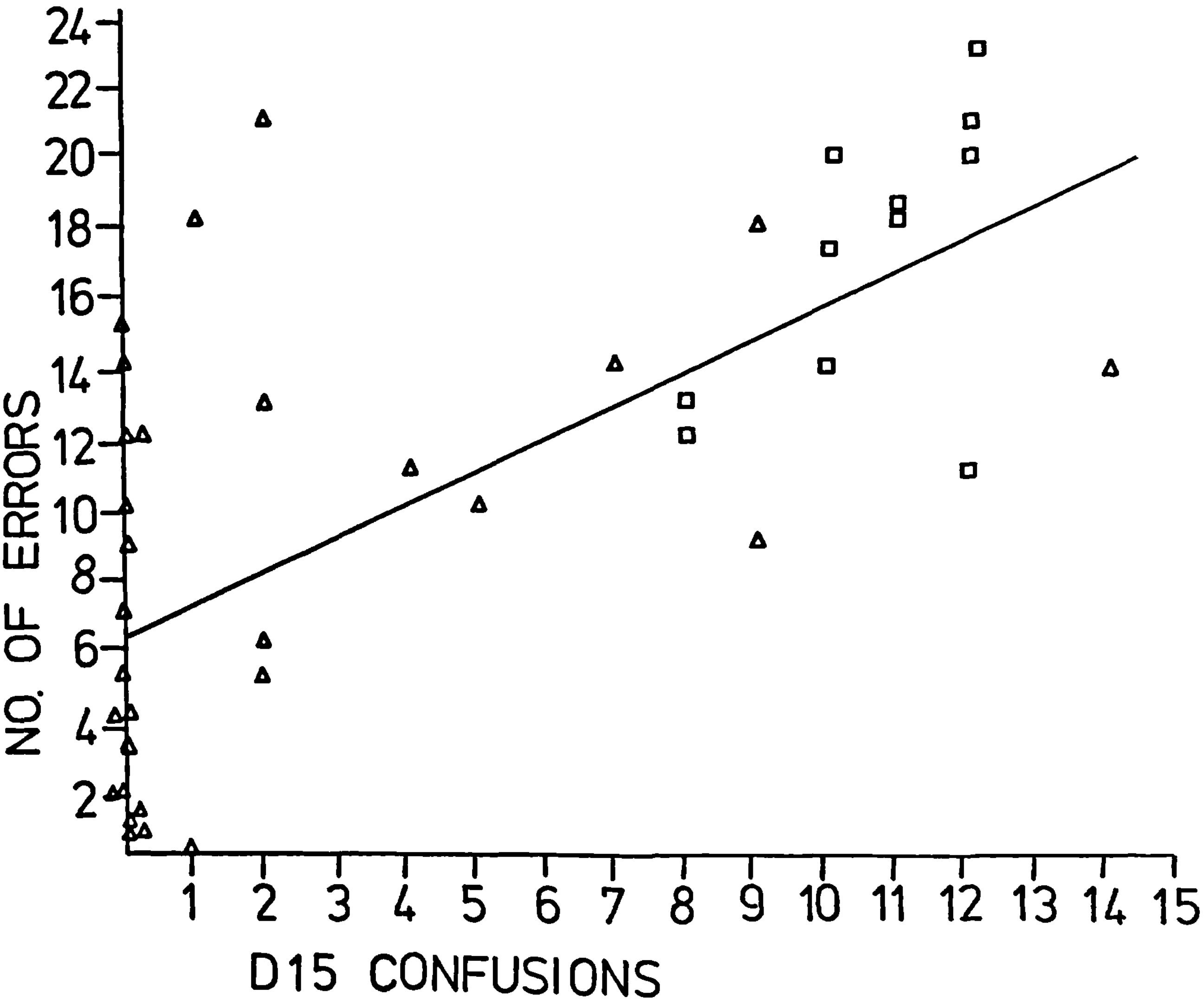


FIG 59
PHOTOFINISHING TRIAL ERRORS
AGAINST H.R.R. ERRORS
SCENE 1

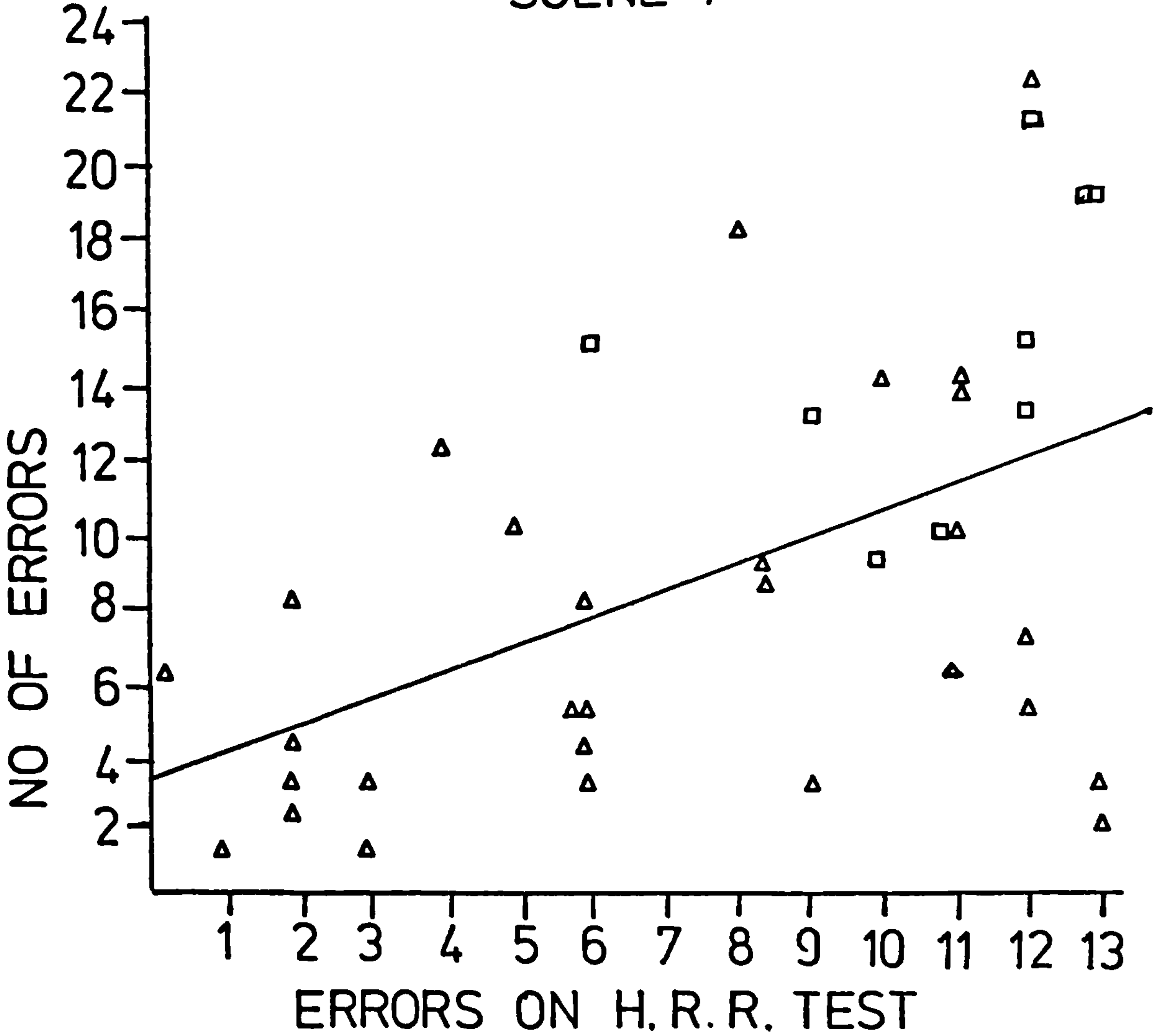


FIG 60
SCENE 2

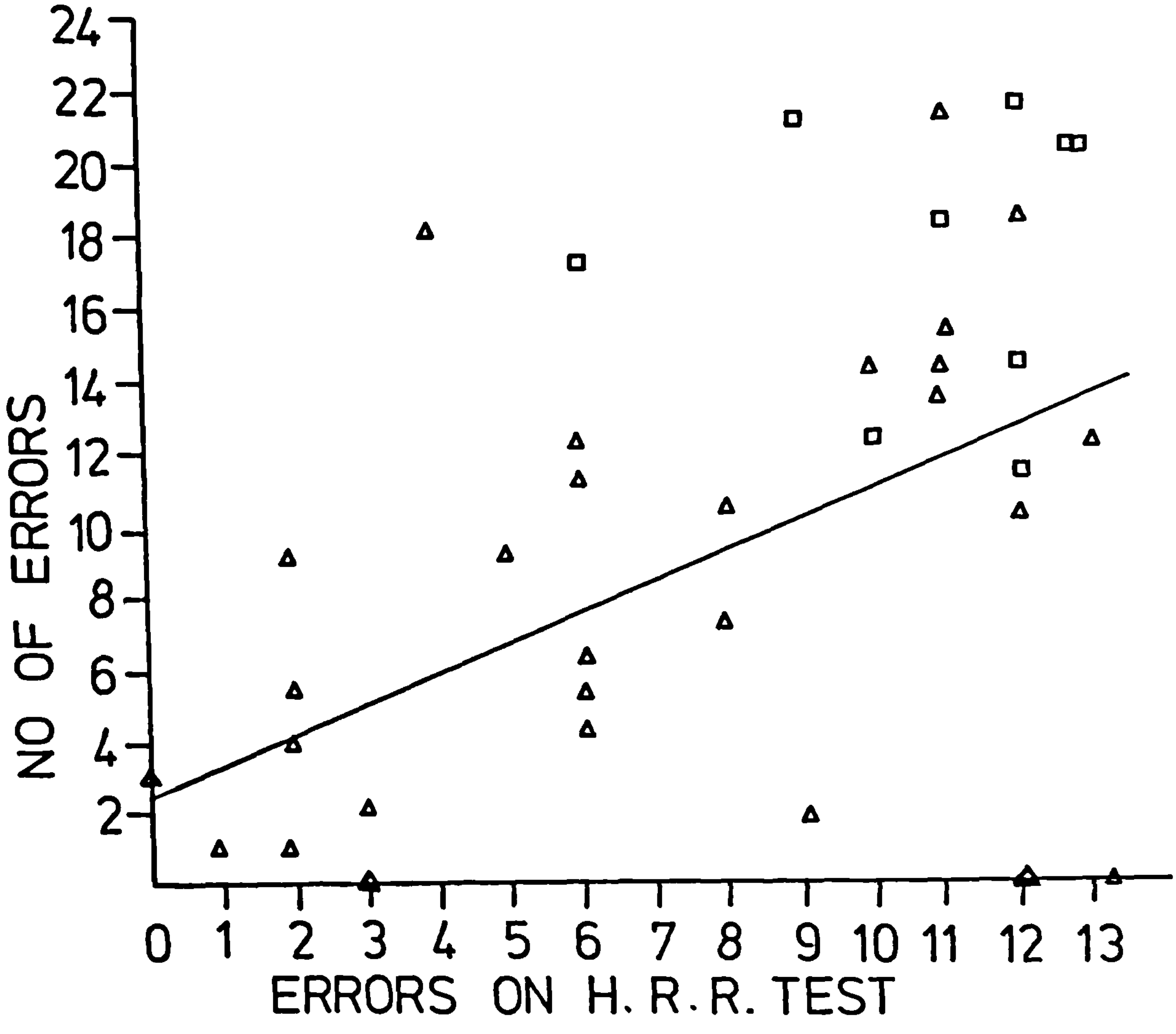


FIG 61
PHOTOFINISHING TRIAL ERRORS AGAINST ISHIHARA ERRORS
SCENE I

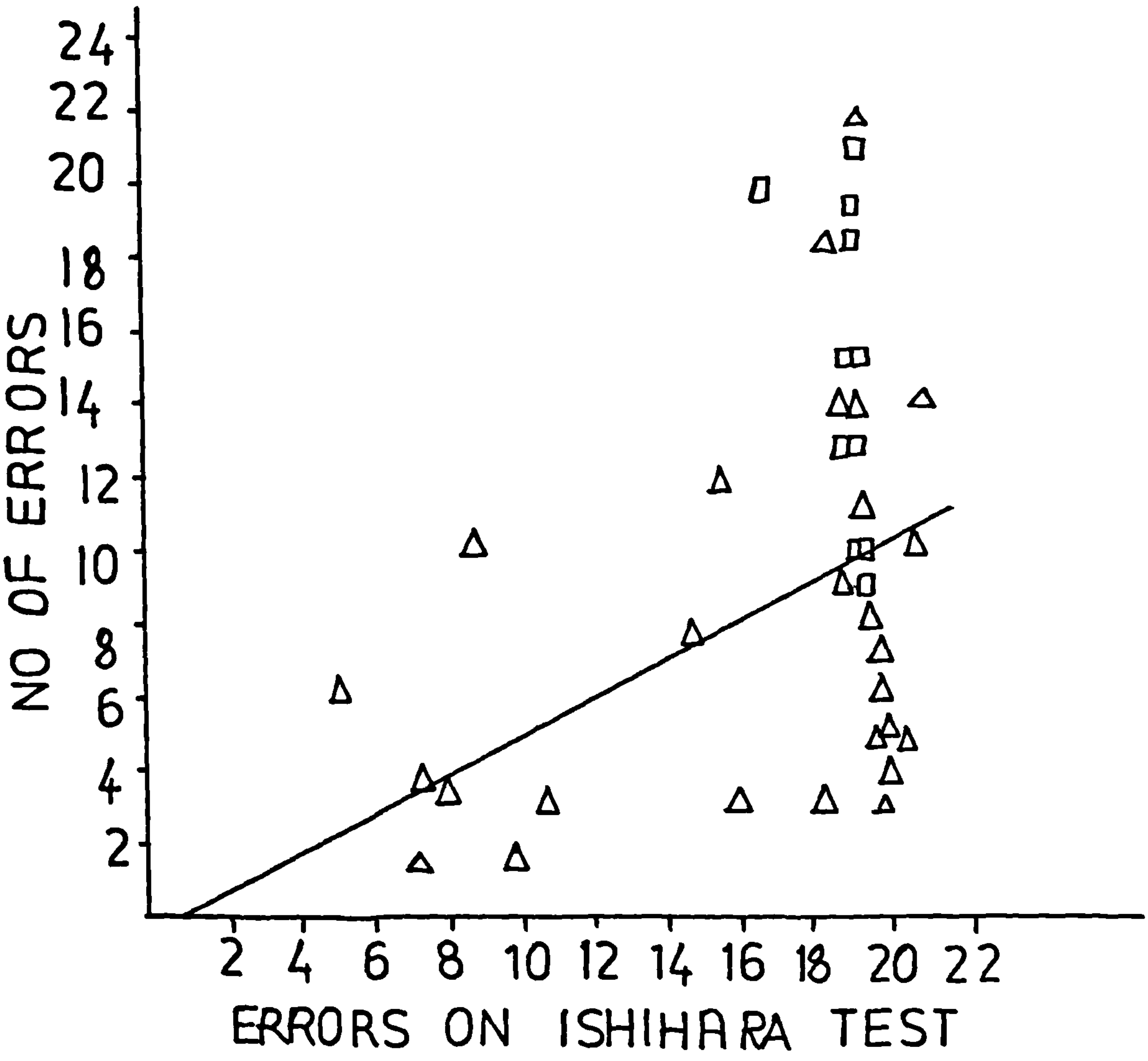


FIG 62
PHOTOFINISHING TRIAL ERRORS
AGAINST ISHIHARA ERRORS

SCENE 2

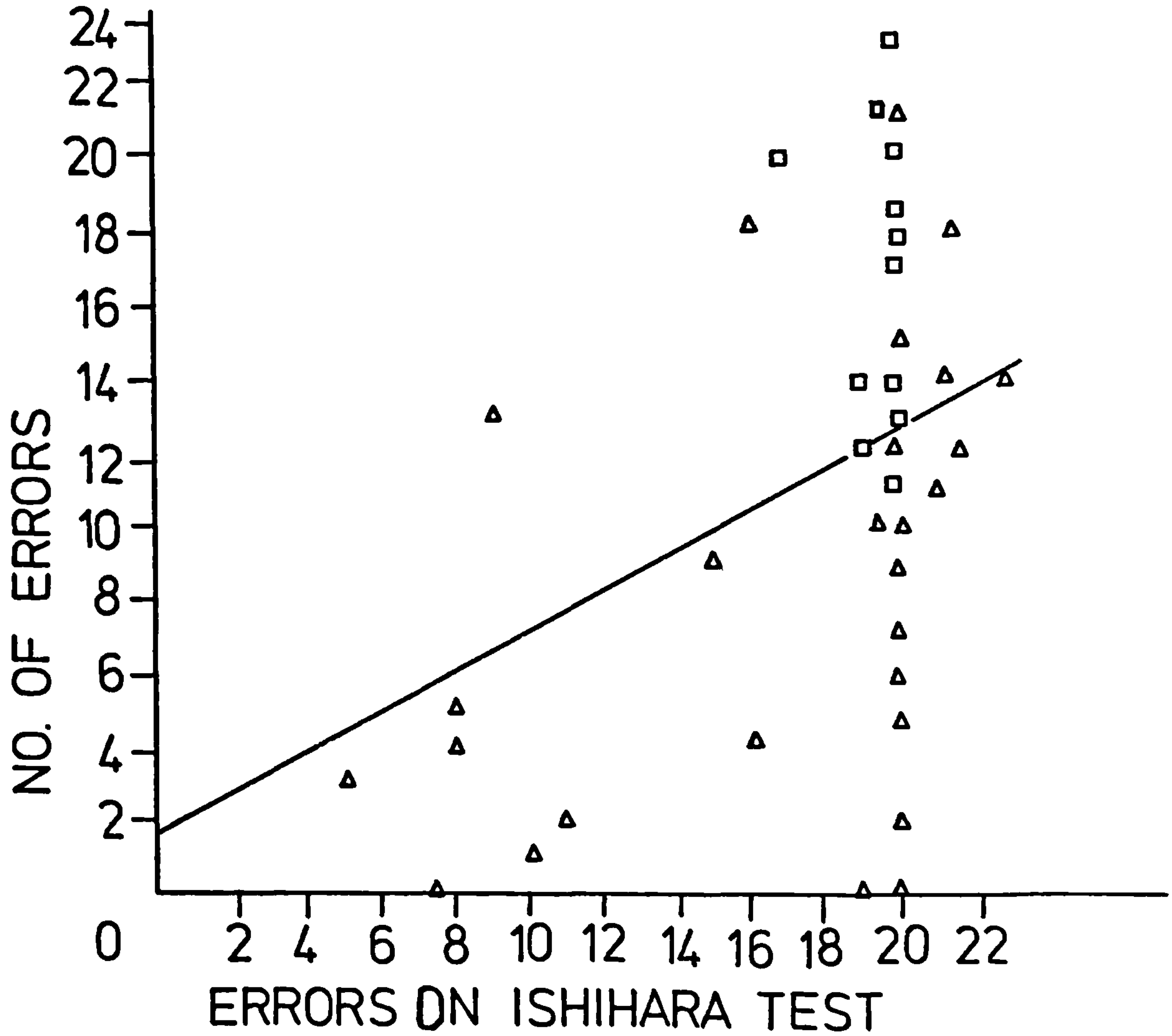


FIG 63
PHOTOFINISHING TRIAL ERRORS
AGAINST NAGEL RANGE

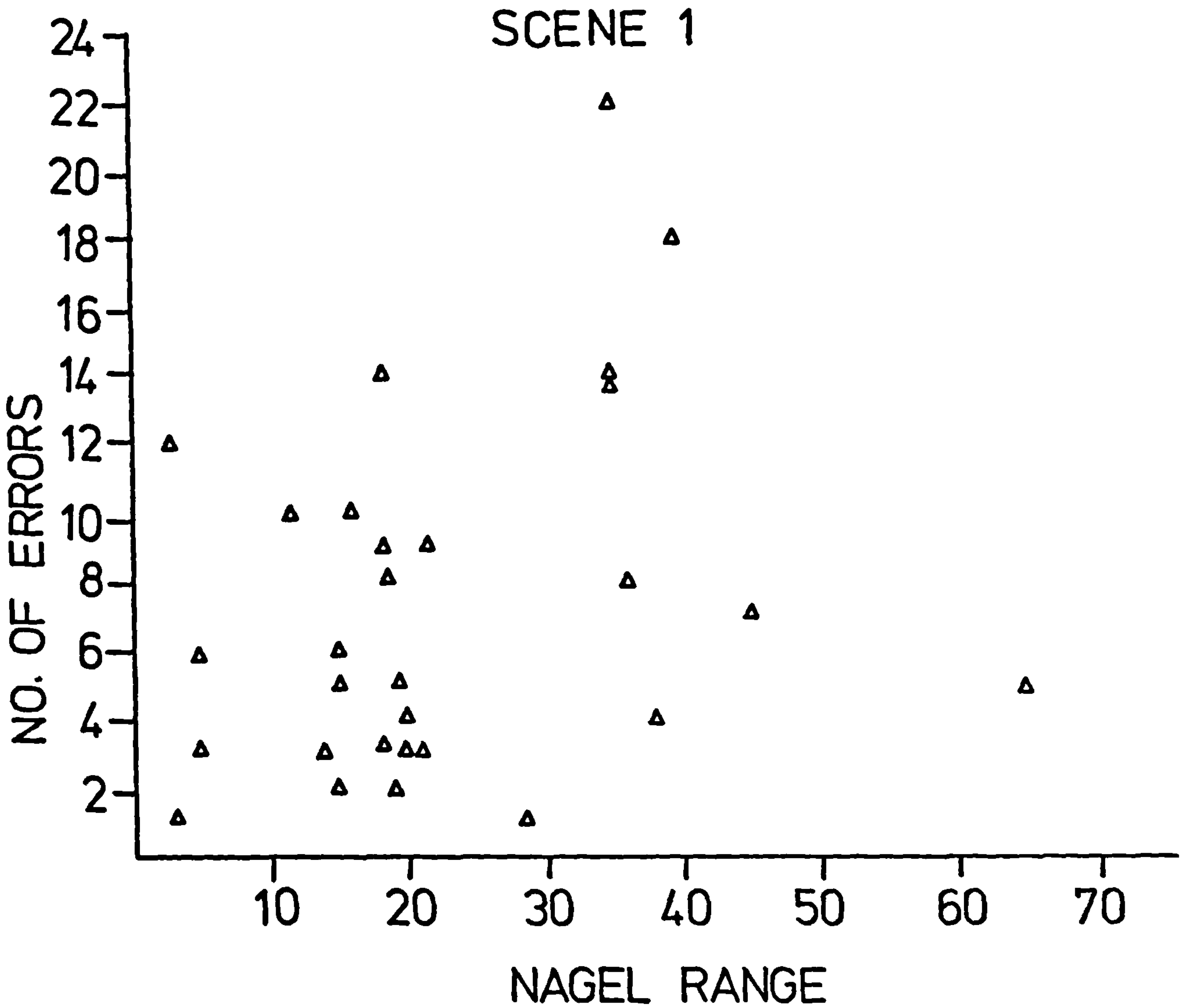


FIG 64
SCENE 2

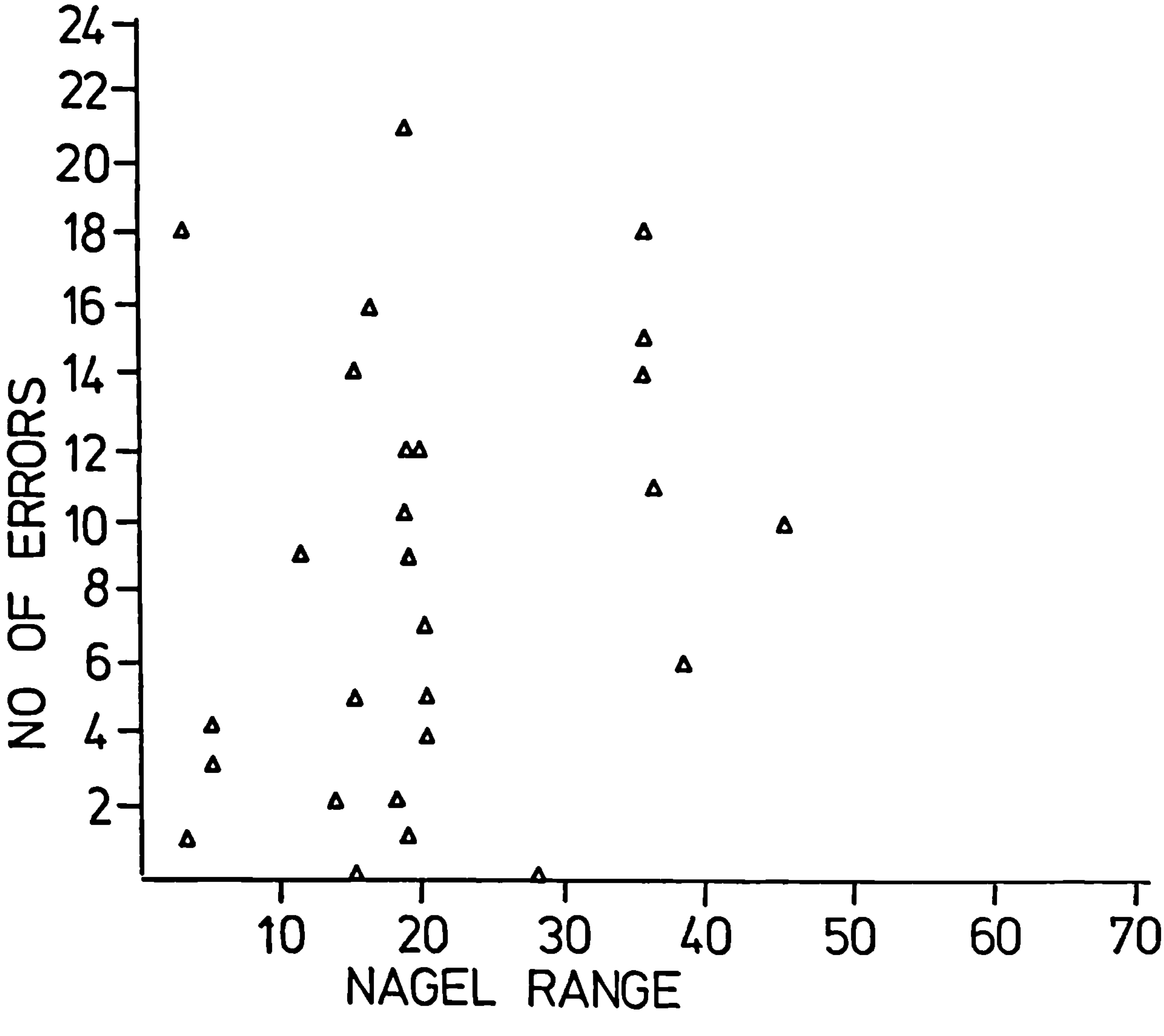


FIG 65
PHOTOFINISHING TRIAL ERRORS
AGAINST AGES OF OBSERVERS
SCENE 1

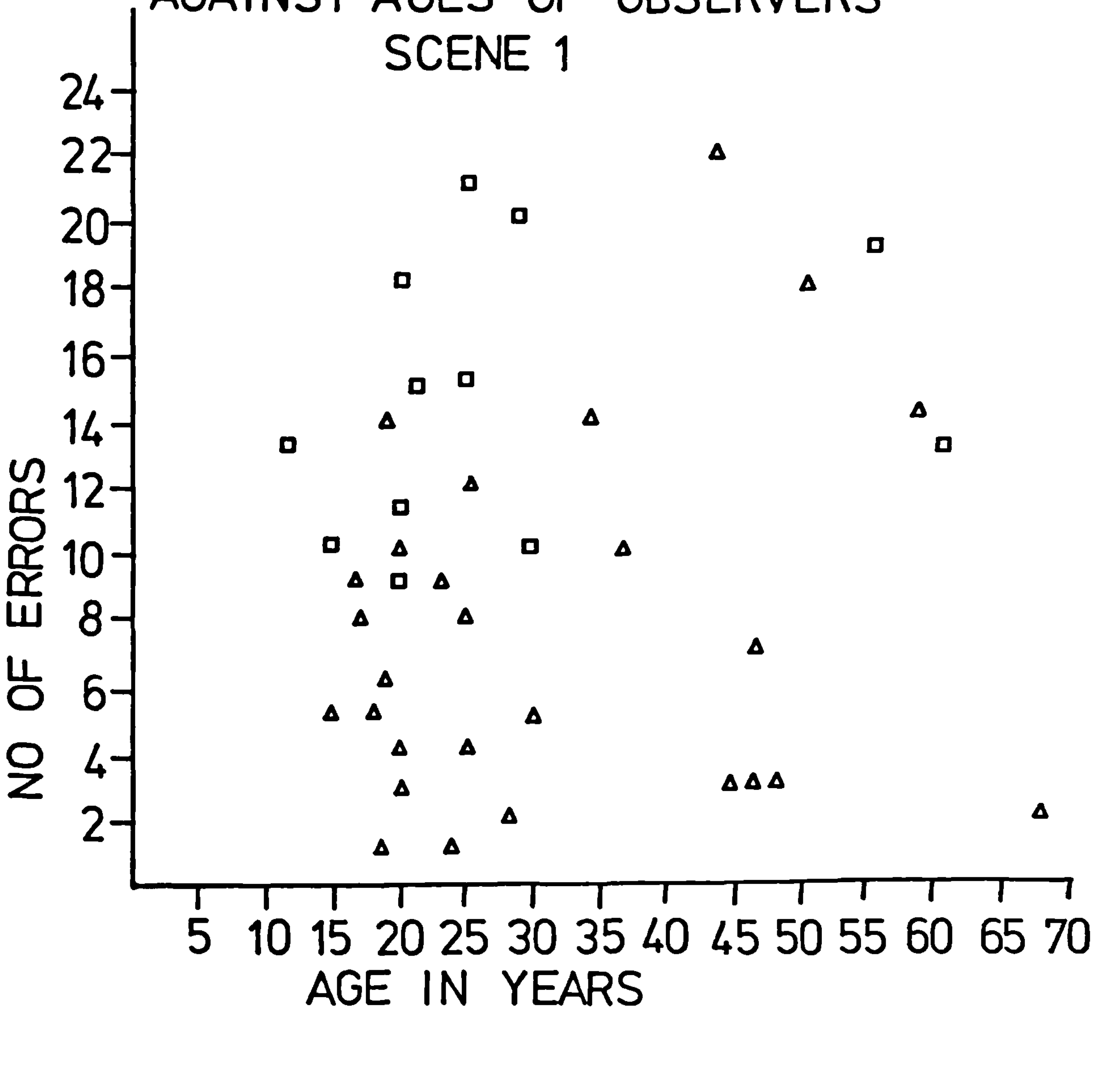
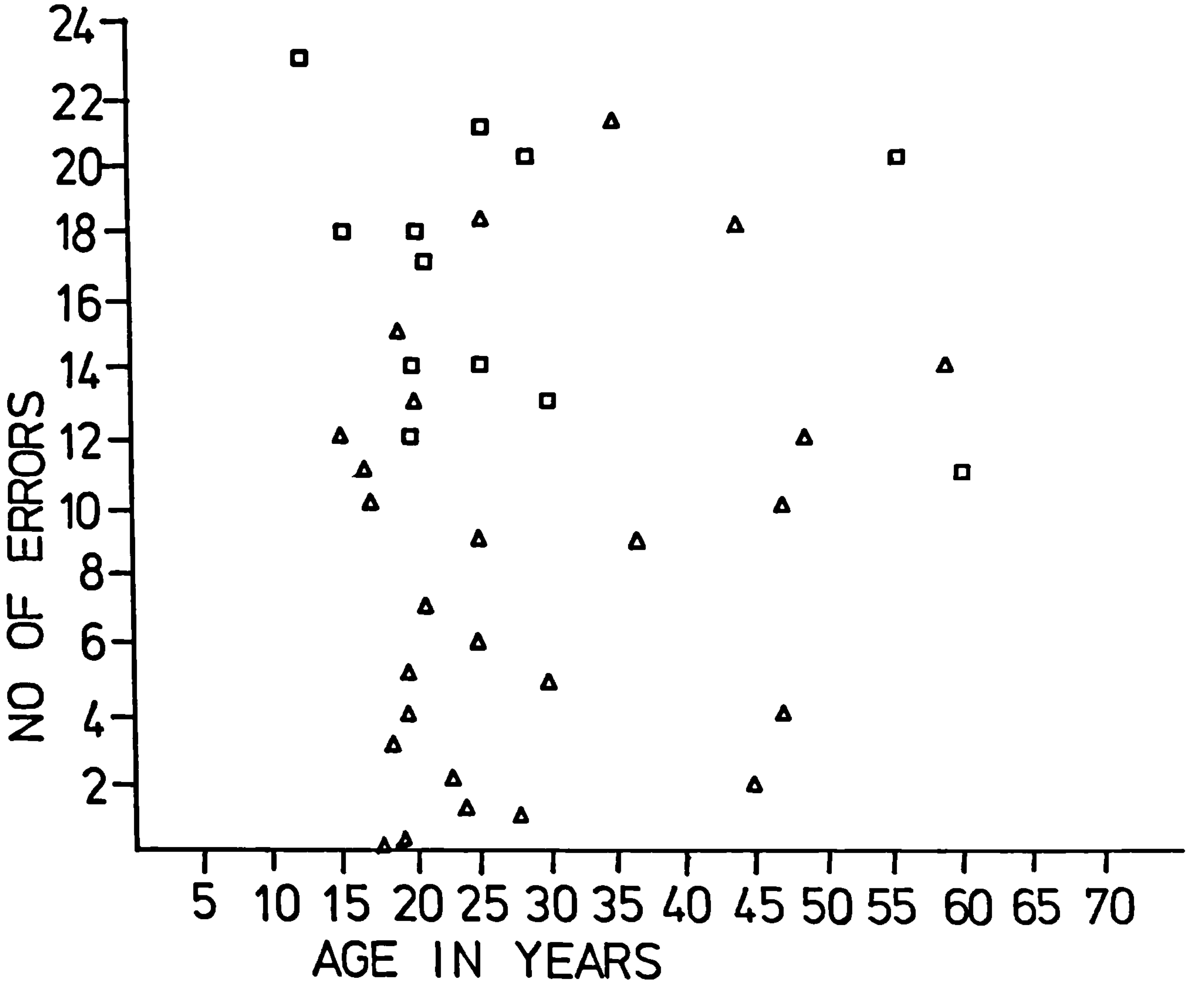


FIG 66
SCENE 2



IV.5

TEXTILE TRIAL

Eighteen sets of plain cloth differing in colour and in type of fabric were provided by Dr. H. R. Cooper of the Shirley Institute, Cotton, silk and Man-made fibres Research Association. The samples, all sizes 5 cm x 5 cm, showed varying E and L values and from these nine sets were selected as material for the trial. Selection was made on the basis of the E and L values, to include some sets showing small ΔE differences and some showing large ΔE differences. Care was also taken to select samples with low ΔL values. This ensured that the main criterion for the judgement was perceived differences of hue (ΔE).

The samples were measured with the Harrison-Shirley digital colorimeter to obtain the ΔE and ΔL ANLAB (40) units.* Selected samples were measured with the Bausch and Lomb spectronic recording spectrophotometer at the City University, to obtain reflectance curves and C.I.E. x, y, chromaticity co-ordinates (see appendix 10).
The colorimetric values of the samples used are given in Table 56
Each set of samples contained four specimens, two which were identical master standards (coded with yellow spots) one which show a commercialy unacceptable colour difference (ΔL and ΔE combined) when compared with the standard (coded with a red spot) and one which showed a commercially acceptable colour difference (ΔL and ΔE combined) when compared with the Standard (coded with a green spot). Dr. Cooper indicated that samples showing a colour difference above o.7 ANLAB (40) units would be unlikely to be graded together in garment-making. Visual comparisons are usually made with full width strips of fabric but this was impractical for the trial.+

Forty-two colour defective observers (two protanopes, twenty-one deuteranomalous six protanomalous, thirteen deuteranopes) and six colour normal took part in the trial. Three of the colour normals were experienced colour matchers working in the dyeing industry. The samples were presented to the observers in pairs in a random order, (the same order for each observer) in a colour matching cabinet (illuminant approximating to standard illuminant C at a uniform level of 500 lux).

*By courtesy of the Shirley Institute

+Correspondence 13 June 1974

No.	COLOUR	ANLAB (40) UNITS			C.I.E. VALUES	
		Acceptable ΔE	Unacceptable ΔE	ΔL	x	y
8	Purple	1.3	4.6	1.3		
15	Violet	1.4	4.4	1.8		
18	White	1.1	3.2	0.3	0.3067	0.3132
13	Green	1.0	2.7	0.7		
9	Red	0.5	2.6	0.6	0.5379	0.3114
5	Brown	0.7	2.5	2.0	0.4592	0.3696
14	Yellow	1.7	2.4	1.0	0.3945	0.3978
4	Green	0.5	1.7	0.7		
17	Grey	1.1	1.7	0.5		

TABLE 56 SAMPLES USED IN TEXTILE TASK

COLORIMETRIC VALUES

Before the trial began the observers were shown the four samples within one set and were told that two were identical standard samples, one was an unacceptable match with the standard sample (large colour difference) and one was a commercially acceptable match with the standard sample (small colour difference). The different samples were identified and observers were asked if they agreed with the classification; in particular agreement was required on the match between the two standard samples and the mis-match between the standard and the unacceptable samples. The observers were told that they would be presented with two samples, side by side, on twenty-one occasions and they were required to indicate verbally whether the samples were a match or a mis-match; no further judgement was necessary. The order of presentation shown on the textile trial sheet, was used for each set of samples for all observers, and the subject's response to each presentation was indicated with a tick (match) or cross (mis-match). After twenty-one presentations the total number of times that the two standard samples were identified as matches and mis-matches, the number of times that the standard and unacceptable match were identified as matches and mis-matches and the number of times that the standard and acceptable match were identified as matches were calculated as seen on the sheet. The results are presented in Figures 57 to 58 .

Conclusions

Colour Normals

In almost every case all the colour normals who took part in the trial considered that when the standard sample was presented with the unacceptably matched sample, a colour or brightness difference could be deteced; on most occasions the equality between the two standard samples was recognised, and opinions were divided almost 50% - 50% on whether the standard sample matched the commercially acceptable sample.

There was no significant difference between the results of the experienced industrial colour matchers and the naive colour normals.

Colour Defectives

Protanomalous Observers

All protanomalous observers tended to reject the unacceptable commercial match, irrespective of the colour difference. On approximately 50% of presentations were the two standard samples accepted as matches, and a similar pattern emerged for the commercially acceptable matches.

Protanopes

The two protanopes rejected almost without exception the unacceptably matched samples. They accepted the two standard samples as matched and were divided almost 50% - 50% on whether the standard sample matched the commercially acceptable samples.

Deuteranomal us and Deuteranopes

The results showed very similar patterns for the deuteranomalous and deuteranopic observers. The unacceptably matched samples were rejected on almost every occasion, the two standard samples were accepted as matches on approximately 70% of occasions and the observers were divided almost 50% - 50% on whether the standard sample matched the commercially acceptable sample.

These results show clearly that colour defective observers are able to detect quite small colour differences in textile samples even when the brightness differences are minimal. In particular ΔE values of 1.7 upwards are readily identified by all classes of defectives. The trial indicates a marked superiority in performance by colour defectives for tasks involving the simple discrimination of colour differences, compared with their naming of colours.

Observer No	Sample no	YY	YG	YR	Sample no	YY	YG	YR	Sample no	YY	YG	YR	Sample no	YY	YG	YR	Sample no	YY	YG	YR
D11	17	4	5	1	4	7	6	5	14	6	1	0	9	6	5	2				
26	17	7	1	0	4	6	4	0	14	7	6	0	9	4	4	4	13	6	1	1
12					4	5	6	0	14	6	2	2	9	6	6	2	18	5	3	3
10									14	7	1	2		-			18	6	3	2
27	17	7	7	3	4	5	3	1												
6									14	7	7	0	9	6	7	2				
13	17	7	7	0									9	5	5	0				
58	17	7	4	0	4	6	6	3	14	3	4	0								
46	17	6	3	1	4	7	7	2					9	6	4	0				
33	17	3	5	0	4	7	7	0									18	6	5	0
50	17	7	5	0					14	6	0	0					18	6	0	0
51	17	7	7	2					14	7	2	1	9	6	7	2	18	6	2	1
59									14	4	0	0								
44	17	2	7	1	4	2	2	3					9	3	4	0	13	2	2	3
66									14	6	3	0								
42									14	6	2	0								
53	17	7	0	0	4	6	7	0	14	7	0	0	9	7	3	0				
54									14	7	5	2								
67					4	4	5	0					9	4	1	1				
68	17	6	4	0	4	3	3	3	14	6	0	0								
55	17	6	7	0	4	5	4	0	14	5	1	0	9	7	3	0	13	7	7	0
43					4	6	5	0	14	6	1	0	9	6	0	1	18	5	0	0
84	17	6	2	1	4	5	7	0												
62	17	6	1	0	4	7	5	0	14	5	0	2								

TABLE 57 TEXTILE RESULTS DEUTANS

Number of times out of seven presentations that textile samples were accepted as matches

YY - Two matches (standards)
YG - Standard + acceptable match
YR - Standard + unacceptable match

Obs NO	Sample	YY	YG	YR	Sample	YY	YG	YR	Sample	YY	YG	YR	Sample	YY	YG	YR	Sample	YY	YG	YR
P19	17	2	7	0	4	6	4	0	14	5	2	1	9	6	4	1				
17	17	6	3	0	4	6	2	3	14	6	1	0	9	6	0	0	13	5	0	5
21	17	6	4	1	4	2	3	4	14	7	4	0	9	6	4	0				
20	17	4	0	0	4	6	6	0	14	5	5	0								
18	17	5	6	0																
22									14	7	3	0								
2	17	7	5	1	4	6	5	4	14	7	4	0	9	6	5	0	18	7	7	0

TABLE 58 TEXTILE RESULTS - PROTANS

Number of times out of seven presentations that textile samples were accepted as matches

YY - Two standards matches
YG - Standard + acceptable match
YR - Standard + unacceptable match

IV.6 COLOUR NAMING TASK

A simple trial was carried out to investigate the colour names given by colour defective observers to the coloured filters used in the Lovibond Colour Vision Analyser. The results are presented in Tables 59 to 61.

Results

The results can be compared to the colour names given in the resistor and capacitor colour naming task carried out in the Electrical Trial. More errors occurred in the identification of the coloured filters than in the Electrical Trial, and this can be accounted for by the difference in saturation of the colours. The colours used for the resistor and capacitor bands are very saturated (see Figure 9) whereas the colours of the filters used in the colour naming trial are relatively de-saturated DAIN (1971). White was always identified correctly in the Electrical Trial but was frequently misnamed in the Colour Naming Trial; the most common confusion for all observers was with green. It is thought that the difference between results can be explained by the high luminance value of the white paint used on the resistors and the contrast with the coloured background of the resistor which was frequently a dark brown. In the colour naming trial white was misnamed on thirty-three percent of occasions by protanomalous observers, sixty-three percent of occasions by deuteranopic observers and forty percent of occasions by deuteranomalous observers.

Deuteranopes

Green was frequently named as brown in the colour naming task (twenty-five percent of occasions) and this confusion was also made frequently in the identification of resistor bands (twenty-two percent of occasions). Green-yellow was called orange on thirty-seven percent of occasions in the colour naming trial. Yellow was often misnamed in the colour naming trial, (thirty-three percent of times it was called orange, thirty-three percent of times green, sixteen percent blue and only on sixteen percent of occasions was it correctly identified as orange). In the resistor naming task yellow was always correctly identified. It is likely that this large difference can be explained by the high luminance value of the yellow resistor/capacitor bands (50.9%), as in the case of white, which aids identification for the colour defective. Orange was frequently misnamed red and yellow (both twenty-five percent of times) and green (twenty-two percent of times) yet only on a total of eighteen percent of occasions was orange misnamed in the resistor trial. The difference in the C.I.E. x value between the resistor orange and the filter orange is of the order of 0.1.

Deuteranomalous Observers

A good record for the correct identification of red was obtained in both colour naming situations. Orange was more frequently misnamed in the colour naming trial than in the electrical trial - in particular confusion occurred with red, green and brown. Yellow was frequently confused with green (fifty-seven percent of occasions) in the colour naming trial but was correctly identified on ninety-nine percent of occasions in the resistor trial. The explanation probably lies in the high luminance value of the yellow used for resistor bands. The misnaming of violet or mauve as blue was frequent in both trials (fifteen percent of occasions in the electrical trial and thirty-two percent in the colour naming trial). The mauve filter used in the colour naming trial was not so readily identified as such by colour normals in the colour naming trial as in the resistor trial, having a bias towards blue. This accounts for its identification as blue on a greater number of occasions.

Protanomalous Observers

Red was confused with brown in both trials. Orange was called brown on twenty-five percent of occasions in the colour naming trial but was always correctly identified on resistors. Yellow was called green on fifty-six percent of occasions in the colour naming trial, and named as orange on eleven percent of occasions. The high luminance value of the yellow used in the resistor bands enabled protanomalous observers to identify this colour correctly. In the identification of the colour filters in the colour naming trial violet or mauve was called blue sixty-six percent of times; frequent confusion also occurred in the resistor naming.

Conclusions

These results confirm that colour defective observers have greater difficulty in identifying desaturated colours than saturated colours - a principle that is well known and used in the design of diagnostic tests for colour deficiency. The comparisons drawn between two different colour naming trials involving colour defective observers serve to re-inforce the conclusion that differences in luminance values assist the colour defective in the identification of colours.

No. of Presentations	Colours as Presented	Red	Orange	Yellow	Green-yellow	Green	Blue	Mauve-blue	Mauve	White	Brown	Black	Grey-green
12	Red	75									25		
12	Orange	8	8	25		8					25		
9	Yellow		11	33		56							
3	Green-yellow			33		66							
6	Green			17		83							
9	Green-blue					100							
12	Blue					33	66						
15	Mauve						66		26				
3	White					33				66			

All figures expressed as percentage of possible namings

Table 59 Colour naming using Lovibond Colour Vision Analyser

Glasses. Protanomalous observers (3)

No. of Presentations	Colours as Presented	Red	Orange	Yellow	Green-yellow	Green	Green-blue	Blue	Mauve-blue	Mauve	White	Brown	Black	Grey-green	Red-green	
60	Red	70	7			10				2	2	4			2	
60	Orange	10	27	27		15						13				
45	Yellow		6	10	10	57					2	9				
15	Green-Yellow	10		10		80										
30	Green	4	6			86		4								
45	Green blue	2				71		6		2	7					
60	Blue					6	7	74		8	2					
75	Mauve	1				1		32	3	55	1	1				
15	White	6				33					60					

All figures expressed as percentages of possible namings

Table 60 Colour naming using Lovibond Colour Vision Analyser glasses - Deuteranamelous Observers (14)

NO. OF PRESENTATIONS	COLOURS AS PRESENTED	Red	Orange	Yellow	Green-Yellow	Green	Green-Blue	Blue	Mauve-Blue	Mauve	White	Brown	Black	Grey-Green
32	Red	62	3			22	3	6			3			
32	Orange	25	12	25	3	22		3				6		3
24	Yellow		33	16		33						16		
8	Green-Yellow		37		13	37					13			
16	Green	6	6			62						25		
24	Green-Blue					67	8	13		13				
32	Blue					6	3	66		25				
40	Mauve	3			5	5		55		33				
8	White					50		13			37			
		COLOURS AS NAMED												

All figures expressed as percentage of possible namings.

TABLE 61 COLOUR NAMING USING LOVIBOND COLOUR VISION ANALYSER DEUTERANOPIC OBSERVERS (8)

IV.7 The Practical Difficulties of Some Colour Defective Observers.

All colour defective observers who took part in the simulated industrial tasks were asked to describe the practical difficulties they experienced in their daily work. Examples are given below:

Nurse : Deuteranope

1. Testing Urine

   Difficulty in matching colour of reactant with a chart.

   [Reactant changes colour as it reacts with urine.]

2. Describing stool colouration - very difficult.
3. Identifying discolouration of faces, particularly jaundice. Cynosis is not so difficult because of other symptoms.
4. Sputum. Difficulty in determining difference between blood stained and plain infected sputum.
5. Vomit. Problems in describing vomit colour and recognising bloodstained vomit.
6. Infacted wounds. Difficulty because of pus colour.

Colour coding

1. Medicines always labelled so no problems.
2. Difficulty in reading charts with different coloured inks especially when green and red are used together.
3. Bottles of blood samples have colour coded tops and the coding identifies the additive. This makes matching easier.

Doctor

"I have a lot of difficulty because I am colour blind, but I compensate with my other senses much as other handicapped people do."

Difficulties with colours of organs, urine and even blood.

"I take great care not to miss the possibility of jaundice, cynosis and usually make the correct diagnosis before other people."

Experiences of colour defective anaesthetist described to me by Dr. H. Whitby, Anaesthetist.

"I remember a protanomalous anaesthetist who is a first-class anaesthetist. I think he learned to draw upon his other faculties and technical aids. He could compensate by using mechanical monitoring devices for the incidence of blood gases of the anaesthetised patient or colorimetric analysis of blood samples. I think this probably holds good in medicine generally. I suppose an occasional situation can be envisaged where colour perception was paramount in diagnosing or at least more critical."

Of an ophthalmologist who was a protanope, he said:

"He was known to have stated that he utilised other criteria, faculties and diagnostic techniques when having to make the more difficult assessments for him in association with varying shades of red e.g. retinal lesions."

Dr. Whitby carried out his own investigations on the effects of fatigue on anaesthetists and found that with one or two individuals gross fatigue probably produced a temporary defect similar to tritanopia, but the result was so evanescent I could not substantiate this."

Ophthalmic Optician : Protanomalous

1. Detecting some pale lens tints and identifying tint colour.
2. Describing some colours used in frame materials.
3. Conducting a colour vision test on a patient.
4. Difficulty in identifying duochrome red-green colours

Ophthalmic Optician : Protanope

Great difficulty in identifying some changes in fundus appearance.

Medical Laboratory Technician : Deuteranope

1. Difficulty with acid-base titrations.
2. Staining of biological material - the most difficult was distinguishing bacteria stained by Gram's method.
   Could be circumvented by choosing counterstain carefully.

Zoologist : Protanope

1. Difficulty in identifying stained sections in slide preparations.
2. Difficulty in dissecting blood vessels.

This observer felt that it was significant that he failed "A" level Biology "due to practical exam", but subsequently obtained an honours degree in Zoology for which he was never required to sit a practical exam involving dissections.

Film making/editing ; Protanope and Protanomalous

Two observers were involved in this work.
Defective colour vision is a bar in most instances.
The Protanope reported that "I have lasted six months with my guilty secret. The more proficient I become, the better aremy chances at overcoming my colour problems."
The Protanomalous observer mentioned that he had trained himself to overcome most of his colour problems. He felt he was able to decide which colour proportions were within the bounds of acceptability and which were not. He made "a mental adjustment". Good colour vision was important for film editing because an assessment of the colour reproduction had to be made when viewing films prior to release.
A detailed account of the employment problems experienced by the protanomalous film editor are given elsewhere.

Auction Salesroom Attendant

1. Difficulty in reading red signatures on green background of paintings.

Accountant

Difficulty in the audit side of the work.
Credit notes were often entered in red ink and were difficult to identify.
"Fortunately with the advent of computerised accounting, one does not need to colour code entries now since an indication of a credit or debit is given by a plus or minus sign, If

this had not been the case it is quite possible that I may have had the embarrassment of advising a client that his bank account was in a healthy position instead of advising him that he was "in the red"."

Brushmaker

1. Difficulty in dyeing brush materials.

Compositor in Printing Industry

Difficulty with colours, - had to work on black and white. Change in colour of ink due to oxidation and pH of paper.

Teacher

Difficulty in describing coloured chalks to pupils.
This observer tells every new class of pupils about his defect so that they are not surprised when he uses the wrong coloured chalks.

Industrial Chemist : Deuteranomalous

1. Identifying end-points in titrations using coloured indicators e.g. screened methylorange which goes green / grey / violet where grey is the end-point.

Electronics Engineer working on colour TV design

Difficulty in setting up a colour TV.
Grey-scale adjustment involves first setting each of the controls, red, green and blue to cut-off ie. adjusting each until it has just disappeared. "When I do this colleagues

say that the red is still illuminated, though I can't see it. I have difficulty in adjusting the three controls to produce a white."

Colour Coding problems experienced by Colour Defectives

1. Documents first amended in red and re-amended in green caused a problem to one observer. He said that he could only follow the amendments if he had actually written them and therefore could recognise his own handwriting.

2. Directions in industry, commerce and everyday life. Comments such as "the red door on the left" caused one observer problems.

3. Colour coding in documents, plans and drawings.

This Section summarises some of the Electrical difficulties involving colour coding experienced by several colour defective individuals.

Cable wires. Difficulty in verbally describing colour of wires.

Red and Brown stripes	)	difficult to identify by
Green and Grey stripes	)	a deuteranope.
Green and Brown stripes	)	

Telephone installation wiring

Difficult with wax-impregnated cotton insulation colour coding. Plastic insulation colour coding causes less of a problem.

Resistors

"Difficult, but not impossible, to distinguish between reds and brown, particularly those with brown backgrounds, and red stripes."

"No difficulty with gold or silver. The first two bands only occur in certain preferred combinations e.g. brown and black or yellow and violet and hence cause fewer problems than they otherwise might. The third band presents most problems, in particular brown and green are frequently confused. This depends a lot on the actual colours used and the ambient illumination. Bright colours and good illumination levels help enormously.

Although I frequently confuse blues and mauves in wiring, this combination does not occur in resistors because mauve is never the third band.

SECTION V
Field Trial

V.1 Colour Vision Testing in a Paper Mill

The opportunity was given to test the colour vision of eighteen colour matchers and two electricans at a Kent Paper Mill using the Ishihara test and the Lovibond colour vision analyser. Restrictions in the time available limited the tests to these two. The Ishihara test was used for screening purposes and the Lovibond test was also used for screening, but primarily to classify any colour defectives and to assess the colour matching ability of colour normals. Natural daylight illuminated the tests.

All the matchers were involved in critical matching of both coloured and white paper. The matching of whites and near-whites was one of the most critical and demanding jobs encountered during the study.

It has been the company policy for the past five years to screen new employees for defective colour vision at the initial interview stage. None of the persons tested had been given a colour vision test before in the company because they had all been engaged before testing was introduced. A good degree of co-operation was maintained between the operatives and management to carry out colour vision testing.

Results

From the sample of twenty, two were found to have defective colour vision (both deuteranomalous) and the test had better than average colour discrimination as measured by the Lovibond Colour Vision analysis. The incidence of two colour defectives in a sample of twenty is about the national average (8%) and is similar to the results obtained by RICHTER (1954) - namely that the proportion of unscreened colour defectives working in industry is the same as the national average.

Colour Normals

1. Young people

Of those who had normal colour vision eight were young people (under the age of forty). Of the young people who were closely involved in critical colour discriminating jobs:

1. One worked on chemical analysis and also made decisions on the matching of whites and coloured paper.
2. One worked with white paper only.
3. One worked with coloured paper only.
4. One worked with colour and white paper.

The lowest saturation settings for the selection of the neutral filter to match the central neutral filter in the test made by the eight young observers were:

Lowest Saturation	
15	1 observer
20	5 observers
25	2 observers

These results indicate normal colour vision and since our experience has shown that most unselected colour normals fail to pick out the neutral below a threshold setting of 25, the results obtained indicate better than average colour vision for six out of the eight young colour matchers. It is likely that experience and familiarity with colour matching tasks accounts for these results.

Some tritan colours were also selected at a threshold level of 15 or 20, in particular the filters no 6,7,8,9 and this is typical of the performance of colour normal observers at this very low threshold setting.

2. Older people

Ten older observers engaged in colour identification took part in the test. Of these:

1. Three worked with white and coloured paper
2. One worked with white paper only
3. Four worked with coloured paper only
4. Two were electricans.

The lowest saturation setting for the groups are indicated in the table below:

Job description	Lowest saturation level for selection of neutral
Matching whites only	15
Matching colours only	20,20,20,20
Matching whites and colours	20,20,20

The results indicate excellent colour discrimination and these results do not show any deterioration in the colour vision of the older matchers, with age.

Colour defectives

The criterion used for classification as colour defective was a failure on at least ten percent of the Ishihara plates and a subsequent failure on the Lovibond colour vision analyser.

Two colour workers were found to be slightly deuteranomalous; one was aware of a family history of colour deficiency and had failed the Ishihara test in the services, the other was unaware of any abnormality in his colour vision. BOth were involved in the matching of white paper against a standard, one as a production worker and the other in a quality control capacity. Both were aged between forty and fifty years.

The coloured filters chosen to match the central neutral on the Lovibond colour vision analyser were both typical of deutan confusions:

Filters chosen	Colours of filters.
No 16	Red
No 3	Light green
No 14	Red
No 2	Blue

The saturation settings involved are given below:

Observer 1	Observer 2
Filter 16 at 80	Filter 3 at 45
Filter 3 at 50	Filter 2 at 45
Filter 16 at 50	Filter N at 80 and 40
Filter N at 50	

As far as is known no action was taken after the discovery of these two colour defectives, particularly in view of the fact that no known mistakes had been made by either of them.

Conclusions

These results confirm that mild colour defectives are working in industrial colour situations involving critical colour situations, and are able to cope with the job adequately.

V.2 Role of Colour Vision in Endoscopic Medical Investigations

Colour discrimination plays a very significant role in the recognition and diagnosis of pathological conditions affecting the alimentary tract when endoscopic techniques of examination are used. Colour is a vital clue because stereopsis is denied under these circumstances and the handling of tissues is also impossible.

Endoscopists showing colour vision defects might be at a serious disadvantage on account of their inability to recognise and identify small differences in hue. The potential problems were indicated when a middle-aged endoscopist, who was known to have deuteranomalous vision, consulted The City University, when he became aware of a different interpretation from his colour normal colleagues. The physician in question had very considerable experience in endoscopic examinations at a London teaching hospital, and realised, after many years, the possible handicap that his colour vision defect might pose.

The opportunity was given to investigate the role of colour in endoscopic examinations, and the possible consequences of colour vision defects, at a two day teaching symposium held at the Middlesex hospital, London, in March 1976 with Professor Fletcher of the City University. Over one hundred endoscopists from all over Britain attended the Symposium. Sympathetic co-operation was expressed by the organisers who allowed an explanatory briefing to be given by Professor Fletcher to delegates at the beginning of the Symposium. A model stomach, similar to those used for teaching purposes, was constructed, and a series of small (3mm and 5mm diameter) coloured, circular targets of Munsell paper were produced by Professor Fletcher. These simulated as far as was possible with the colour range available, lesions found in the alimentary tract. The targets were chosen to include a number of likely confusion colours for protan, deutan and tritan observers, bearing in mind also the colours found in tissue of this nature. Colour defective delegates at the symposium and some colour normals were invited to view the targets through an endoscope using the model stomach, and to indicate how many spots were visible in each presentation. A score sheet similar to that used with The City University Colour Vision Test was provided for the results (see attached sheet).

A questionnaire, inviting comments on the role that colour vision plays in endoscopic examinations, was distributed among delegates who carry out endoscopic examinations routinely. A copy of the questionnaire is given on page 472 .

<u>Results of questionnaire</u>

Seventy-two questionnaires were completed.

1. Have you ever had a colour vision test?

Fifty-nine percent of delegates had not had a colour vision test before and were given the opportunity at the Conference, using the Ishihara and The City University tests. The tests were illuminated by artificial daylight provided by a Macbeth lamp. Sixty-seven forms were completed by colour normals and five by colour defectives - all slightly deuteranomalous as far as could be indicated by the tests used.

2. Did you have a colour vision test before you started medicine or during your training?

Of the thirty-nine persons who had previously been tested, twenty-one (fifty percent) received a test during their medical training (usually as part of a physiology course), eight (twenty percent) had had a test before their course (usually at school or in the forces) and one had been tested after he qualified. Three gave no information. Four out of the five colour defective endoscopists also became aware of their colour vision abnormality when a test was given during their medical training. One was aware from an early age of difficulties with colours.

3/4 Do you have any difficulty in identifying colours? If yes, is it a handicap for endoscopy?

Only three colour defectives reported having difficulty.

in identifying colours, and only one felt this was a slight handicap for endoscopy.

5. <u>If you have a colour vision difficulty does this extend to other medical tasks?</u>

One colour defective reported difficulties; this concerned the identification of cyanosis. In practice this was not felt to be important because the supporting staff knew of the colour vision defect. The same doctor reported being able to see scars better than colour normals.

6. <u>How does colour play a role in endoscopy</u>?

The answers to this question provided much valuable information. Almost every person considered colour to be a very important aspect in diagnosis. One person noted that since endoscopy is totally qualitative only colour adjectives are used. The most usual colours mentioned were reds, yellows and some blues. Several people mentioned the importance of colour contrast, and the lack of three dimensional vision which meant further reliance on colour. One person indicated that colour was an essential feature of diagnosis, another felt that colour aided recognition, but was not essential. Several replies indicated that defective colour vision would cause difficulties. One person mentioned:

> "Diagnosis-ability severely handicapped without colour vision."

and another:

"A defect in colour vision would not help to differentiate between normal and abnormal tissue."

Colour was used in the following situations:

1. Distinguishing between normal and abnormal mucosa - normal mucosa is pink.
2. Assessing the nature and severity of some lesions.
3. Assessing the degree of inflamation by redness.
4. Identifying small ulcers, gastric neoplasms and some early cancers.
5. Distinguishing between bile and blood.
6. Identifying pale lesions and haemorrages.
7. Assessing degree of severity of some diseases.

Ulcers are often grey or yellow or slightly green with a red surround and it is clear that many lesions are identified by slight colour changes.

7. Do different instruments give apparent colour differences? (e.g. with a given lesion?)

The opinion on this question was divided almost equally. Twenty-seven respondents thought the answer to be yes and twenty-nine, no. Eight did not know, in most cases because of lack of experience with different instruments. Several people mentioned that apparent colour differences were noticed because of a difference in the illuminants. One person noted that the older the instrument, the more yellow the rendition. The five colour defectives were equally divided in their opinion. Two thought that differences did occur, two thought not and one did not know.

8. <u>Can you name any endoscopes which give good or bad colour appearance?</u>

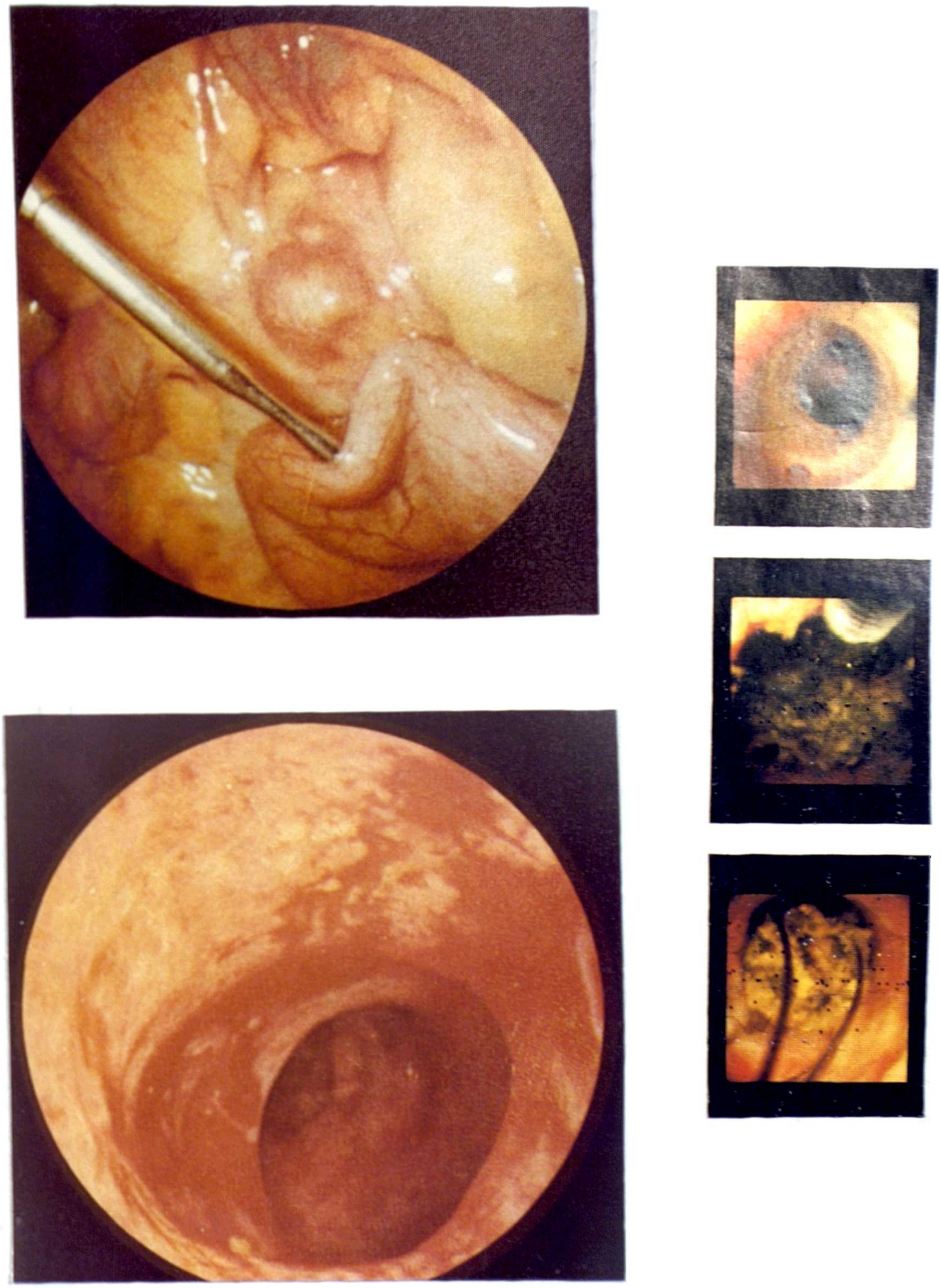
Most people, including the colour defectives, thought that the Olympus instrument gave a better colour appearance than the A.C.M.I. model. A few respondents noted that the Olympus model gave a yellow colour rendering and the A.C.M.I. a blue appearance.

It appears from these comments that colour plays a very considerable role in endoscopic examinations and is useful as a clue for diagnosis of many pathological conditions. The colour defective is at a considerable risk in observations of this nature and is likely to miss vital colour clues if the defect is pronounced. Three of the five colour defective endoscopists who were contacted, reported having difficulties, and all five only showed slight green defects.

The results obtained with the endoscopic test (3mm size) produced by Professor Fletcher for use with the model stomach, were not entirely conclusive. The three colour defectives who took part gave rather mixed responses. One identified all targets correctly, a second gave one deutan response and six normal responses and the third gave one deutan response, six normal responses and two which were inconclusive.

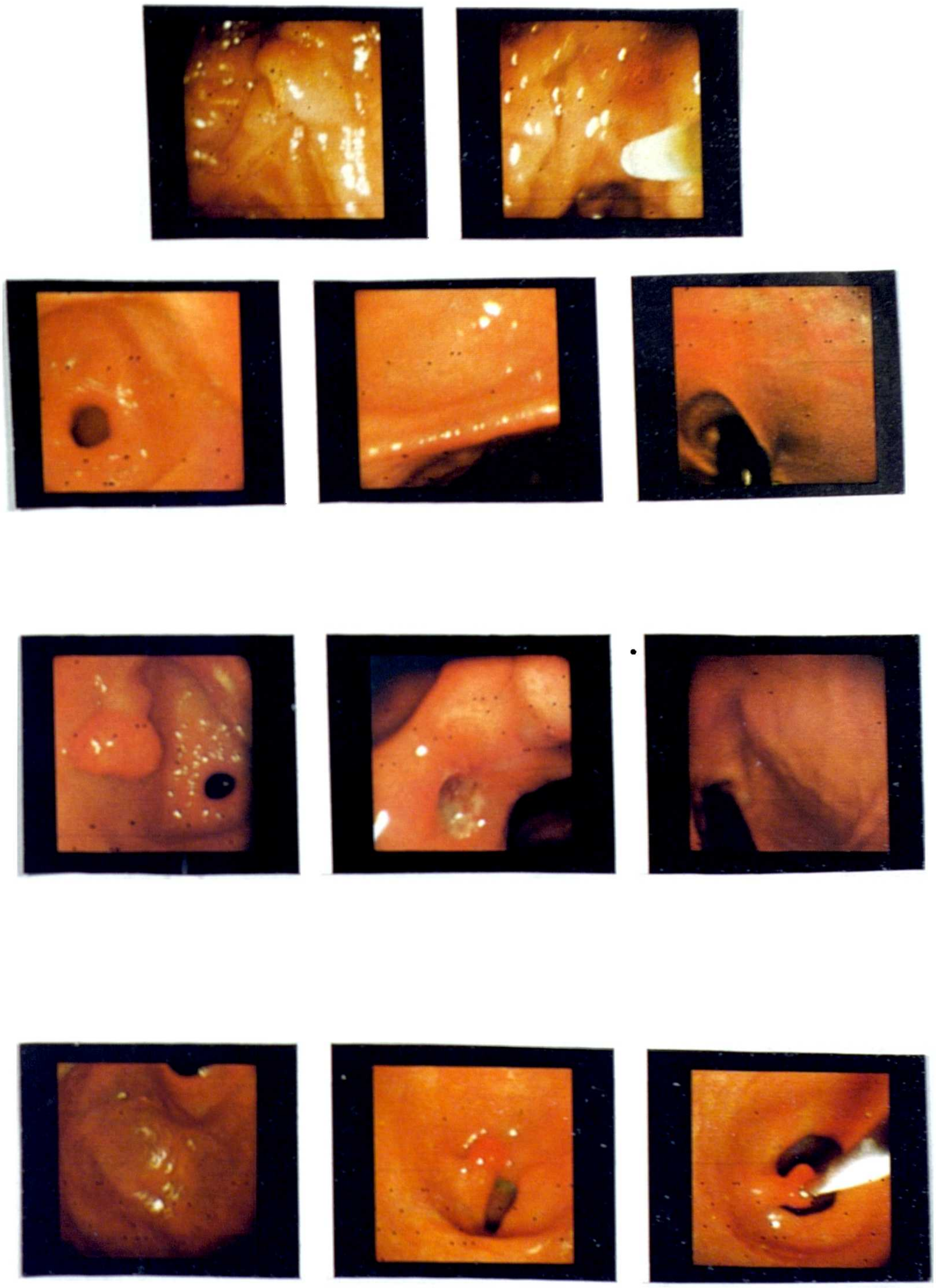
Two deuteranomalous observers took part in the 5mm spot identification test. One gave four normal responses, two protan responses, two deutan responses and one tritan response. The other gave nine normal responses and one deutan response. The colour normals who took part in both tests performed well, giving the correct answers in most cases. Further examinations with the new test are needed before general conclusions can be made.

Medical Specimens



These photographs were taken through an endoscope used for internal examination of digestive tract. They demonstrate the role of colour in medical diagnosis.

Medical Specimens



These photographs were taken through an endoscope used for internal examination of digestive tract. They demonstrate the role of colour in medical diagnosis.

SECTION VI

VI.1 COLOUR VISION TESTING IN SCHOOLS

The desirability of testing the colour vision of children in schools has been recognised for some considerable time. In the 1946 Report of the Physical Society on Defective Colour Vision in Industry a whole section was devoted to this aspect as the bearing it has on the industrial situation is considerable. The Committee responsible for the Report recommended that

> "all children should be tested at school at the age of thirteen or over using one of the approved confusion chart tests".

The recommendations were supported by the views of many industrial concerns who were contacted throughout the study.

The importance of testing children for defective colour vision, and the linking up of this information with the Youth Employment Service was mentioned in the Annual Report for 1934 of the Chief Medical Officer of the Board of Education. He stressed also the industrial handicap which affects many colour defectives, and the fact that

> "the testing of colour vision is not included as one of the routine activities which form part of an ophthalmic service".

The present writer considers that a colour vision test should be available to all as part of the eye examination carried out by ophthalmic opticians and ophthalmic medical practitioners under the National Health Service. Considerable efforts are being made in the ophthalmic departments of some British Universities to emphasize this responsibility to students who will become the ophthalmic opticians of the future.

The question of testing the colour vision of children at an early age in schools was raised by Rear-Admiral Beamish in the House of Commons on an amendment to clause 46 of the 1944 Education Bill. He argued that since a number of careers are "completely closed" to the colour defective, the early discovery of such a defect was of considerable importance to a child. In his reply, the Minister of Education, Mr. R.A. Butler, said that he had taken steps to see that the needs of the colour defective child were brought to the attention of doctors through the nurses and school-teachers.

In 1968 the Society of Dyers and Colourists wrote to the Department of Education and Science suggesting that a test for defective colour vision should be part of the school medical service and that a pupil should receive guidance according to the severity of the defect.[1]

1. Letter from Mr. K. McLaren to the Editor, The Sunday Times 14th August, 1973

Thus it appears that the case for the school testing of colour vision has received reasonable attention in the past. Indeed some counties have been testing the colour vision of schoolchildren formany years. The Annual Report of the Medical Officer of the Lancashire County Council for 1933 contains a section on an investigation into "colour blindness among elementary schoolchildren". Reports[2] are also known relating to the colour vision testing of both boys and girls in Worcestershire and Staffordshire around that time.

Colour vision screening in schoolchildren in England is now a widespread practice (see also results of postal survey reported in this section). As such there is no standard practice in relation to the testing of children for defective colour vision in England and Wales[3] and school medical examinations are the responsibility of the local education authorities. The Department of Education and Science, however, indicate[4] that the majority of local authorities carry out a colour vision test on schoolchildren after they have reached eleven years of age. They encourage the test and provision is made for it on the official school medical card used by authorities.

2. Information given without source of reference in the Report on Defective Colour Vision in Industry (1946)

3. Letter to Mrs. J. Poplett, 4th June 1974, from Medical Advisor to the Greater London Council, Inner London Education Authority

4. Written communication to Dr. M. Tordoff, The Society of Dyers and Colourists from F.W. Beale D.E.S. 26th July 1968

A section devoted to colour vision appeared in a report published in 1971/2 by the Chief Medical Officer of the Department of Education and Science on the Health of the Schoolchild. It was found that colour vision testing, using the Ishihara test plates or vision screening machines, was performed in all but five authorities in England and Wales. Routine colour vision testing is also carried out in Scotland (Scottish Home and Health Department 1962). Twenty-seven authorities in England and Wales repeated the test at some stage.

In this study the age of testing was found to vary from five years to fifteen years. This is similar to the results obtained by the present writer in 1976. The report noted that sixty-seven percent of authorities test for defective colour vision between the ages of nine and eleven years. In the present study it was discovered that fourteen percent of authorities tested between the ages of seven and nine years, and sixty-four percent between the ages of ten and twelve years. In the 1971/2 study it was noted that twenty-one percent of authorities elect to test colour vision at the age of fourteen or fifteen (compared with only eight percent between the ages thirteen to fifteen in the present study). TAYLOR (1971) reports that colour vision testing in Ayreshire Schools usually takes place at the age of twelve or thirteen.

In an earlier paper TAYLOR (1966) asked what age is most helpful to test the colour vision of a child. Together with GALLAGHER AND GALLAGHER (1964) and BACON (1971) the general opinion seems to favour some form of test on school entry, although THULINE (1972) suggests a pre-school test. There is no doubt that a preliminary test of colour vison around the age of five years is advisable in view of the use of colour in teaching methods for infant and primary children. It is considered that the recommendation made in 1946 by the Committee of the Physical Society in their Report on Defective Colour Vision in industry to test at the age of thirteen or over is now out of date. GALLAGHER AND GALLAGHER (1964), have reported, however, that a five year old child cannot cope adequately with a colour vision test which depends on the recognition of numbers; shapes, such as are used in the A.O. H.R.R. plates are more appropriate. Comments made by Specialists in child health reveal a widespread dissatisfaction with the tests currently available for screening young children, and the development of an ideal test for this age-group is obviously a major priority.

BACON (1971) considers that despite a low incidence (0.4%) of colour vision defects in females, the testing of girls is justified. The 1971/2 Report mentions only twenty-five percent of authorities as testing boys only; the 1976 study indicated a similar proportion (twenty percent). Thus it appears that in general, girls receive a colour-vision test with the boys.

The need for advice

It is evident that some form of advisory clinic for colour defectives, in particular children whose career choices may conflict with their handicap, and adults who experience trouble with their work, are needed in at least the major cities of the U.K. Consultant ophthalmologists are usually too busy to be able to carry out extensive testing and offer appropriate advice for colour defectives although one or two known to the author have taken a special interest in this aspect.[5]

The only tru ly advisory occupational clinic for colour defective children known to the author is at Heathfield Hospital, Ayr, Scotland which is run by Dr. W.O.G. Taylor, Consultant Ophthalmologist, and two medical assistants. The clinic, which seems to be unique in the world, was started in 1965 through the vision of Dr. Taylor. He contended (1966) that since routine colour vision testing was undertaken in Scottish schools, special consultative clinics should be established so that advice given to those found to be colour defective should be as meaningful as possible. Between the years 1965 and 1970 nine hundred and four children were examined. Of these, seventy proved to be colour normal and three had blue-yellow defects. A total of eight hundred and thirty one (776 boys and 58 girls) showed red/green defects. Most of the children referred were between the ages 13-15, by far the largest number being aged 14.

5. e.g. Dr. M. Sarwar, Oxford Eye Hospital

Taylor has been particularly concerned with the career aspirations of colour defective children. Of all the children examined, sixty-seven percent of boys and seventy-three percent of girls had decided on a future career. Of the three hundred and thirty-seven fourteen year old boys (the largest age group) seventy-one percent had chosen their career.

From those who had chosen, a division was made into 'suitable' and 'unsuitable' based on the recommendations of the Careers Bulletin of the Youth Employment Service (1966). Table 62 shows the results Taylor obtained in each group.

	Male			Female	
Age	Suitable	Unsuitable	Age	Suitable	Unsuitable
10	3	12	10	-	-
11	14	15	11	0	3
12	16	20	12	3	7
13	42	55	13	2	1
14	86	164	14	4	9
15	22	31	15	3	6
16	5	9	16	-	-
17	9.	18	17	2	1
18	2	4	18	1	0
	199	328		15	27

Table 62

A total of three hundred and fifty-five, sixty-two percent, had chosen an unsuitable career and two hundred and fourteen a suitable career. Alternatives were given in a few cases, but these were mostly unsuitable ones. TAYLOR (1971) divided the unsuitable careers into groups - those which would be a definite bar for a colour defective and those which were unsuitable because defective colour vision would be a major or minor handicap. The numbers of colour defective children who chose careers in these categories are:

1. Minor Handicap (81 children)
   e.g. gardener, farmer, teacher, nurse, hairdresser, carpet fitter, draper, baker, confectioner, barman
2. Major handicap (145 children)
   e.g butcher, chemistry teacher, bio-chemist, industry chemist, electrical work, doctor, pharmacist, carpet designer or darner, printer, window dresser, photographer H.M. Customs Preventive officer.
   TAYLOR (1971) stresses that difficulties might arise in these occupations with even a slight colour vision defect, although it might still be possible to overcome these with determination.
3. Definite Bar
   e.g. Navigation, Traffic Control, Police, Officer in Forces, Radio-telegraphy, Railways, electrical work in GPO and Railways.

Fo rty-three children did not specify their career choice exactly enough for inclusion in the above groups and in fifty-six cases the exact task was not specified e.g. farming, retail trade.

TAYLOR (1971) considers that the degree of difficulty which is likely to be encountered in a particular occupation has to be weighed against the severity of the colour vision defect. He also stresses that it is important to remember that what might be a major handicap during a training period may only be of minor significance once the individual is trained i.e. it may be possible to avoid certain branches of an occupation in which the defect would cause problems. He recommends that the advice given to children should take account of:-

1. The effect of the defect on schooling. This is particularly important in the following areas:
    1. Teaching methods using colour in infant schools e.g. Mathematics
    2. Colouring of maps in geography/geology
    3. Needlework - selection of cotton
    4. Chemistry - identification of chemicals, colour changes in reactions and titrations.
2. The effect during the period of training
3. The effect on performance in the actual task
4. The safety factor

Recently an attempt has been made by Taylor to follow up the previous patients who had now reached the age of twentyone, to inquire what career they had, in fact, taken up; what colour content it had and whether or not they thought that their defect had affected their career.

One hundred and seventy-two colour defectives returned a questionaire sent in October 1974 to enquire about their present employment. The sample contained one hundred and twenty-eight deutans and thirty-nine protans who had a significant defect. Of these fifty-one had dichromatic vision. Fifty-five percent did not consider colour judgement to be of any importance in this occupation and few experienced problems in their work with colours. Slightly over fifty percent of the male patients had changed their career choice on the basis of advice given at the clinic.

The only other facility similar to the Scottish Advisory Clinic available to colour defectives was set up in April 1964 at The Department of Ophthalmology Saisei-Kai Kyoto Hospital in Japan. In a Japanese paper HUKAMI (1970) reports on the studies made on five hundred patients seen during the years 1964-9. The most common ages of patients were in the groups six years (school children), eighteen years (age for advancement to higher education) and twenty-one years (age for job application after higher education). It is unfortunate that no details are given on the careers followed by the patients or the advice given. SARWAR (1970) refers to seeing colour defective children in his ophthalmic clinic at Oxford Eye Hospital, but this was part of the general service offered and the numbers seen were small.

Postal Survey

A questionnaire (see Appendix 3) was circulated to the one hundred and one specialists in community medicine (Child Health) acting for the Area Health Authorities in England. The aim was to discover whether or not colour vision testing was a widespread practice, and in particular what career guidance facilities (if any) are available to colour defective children. The early detection of a serious colour vision defect in a child is an important factor in career guidance.

The degree of co-operation obtained in supplying this information was greater than had been expected, and with a discrete reminder in a few cases, where appropriate, it was possible to obtain a hundred percent response rate. The results are shown in Table 63 and in graphical form in Figure 68.

Conclusions

It was pleasing to discover that all authorities test the colour vision of school children. Most authorities (seventy percent) screen girls as well as boys. In the majority of cases, (seventy-six percent) the school nurse conducts the test, but often the doctor is responsible or is present at the colour vision test. The doctor is present in thirty-eight percent of cases.

Choice of Test

The Ishihara test is the most widely used test in some form (in ninety-two percent of cases). The Keystone visual screener, which includes a brief colour vision test using selected Ishihara plates, is used on a wide scale in schools for general visual screening purposes, and in thirty-one percent of authorities this is the only colour vision test given. More usually the Keystone screener is used for new school entrants (between the ages of four and six years) and the Ishihara test is given separately at eleven years. The Guys and Bacon tests are sometimes used for very young children e.g. school entrants at about the age of five years. This is the standard policy in nine percent of authorities. In fourteen percent of authorities a colour vision test was repeated after three, four, five and six years. One authority used the Ishihara test on three occasions during a child's school career.

It is to be regretted that in many cases little thought seems to have been given to the choice of test. Very often the test is "inherited" from predecessors and its use continues without further consideration of the possible alternatives. In thirty-two percent of cases "historical reasons" were mentioned for the choice of test. These comments were typical:

> "choice was made before my time - no details"
>
> "we have used the test for more than twenty years and no one remembers how the choice was made."

"Reasons for choice buried in antiquity!"

Ishihara test was the only one available."

Only one authority mentioned that the choice had been made by an examination of the alternative tests available, a study of the literature, and personal enquiry at Moorfields Eye Hospital. Another authority had chosen the Ishihara test because of the ease of carrying out the test.

There were several conflicting views on the suitability of the Ishihara test. One authority mentioned:

"Experience shows that the Ishihara is the best and the most universally accepted test."

another reported:

"Ishihara we believe is very accurate"

whereas another felt:

"There are few, if any, really satisfactory tests for school entrants."

Although the Keystone screener has a number of attractive qualities for general visual testing, many authorities did not consider it to be perfect for the proper colour vision examination. One authority mentioned that they used the Keystone screener because of the extreme difficulty in obtaining the services of consultant Ophthalmologists. They used the Ishihara test on on those who failed the Keystone colour vision test.

Several people pointed out the desirability of testing for defective colour vision at an early age, particularly in view of the widespread use of colour in teaching methods, e.g. coloured rods in mathematics. But few were satisfied with the tests available for young children. Several authorities had tried the Guy's test or Bacon test, but they had found the Ishihara tracing paths to be more satisfactory. One specialist in child health was interested to know if there were plans to devise a more satisfadory test for young children. In her experience, the school entrant could not easily cope with the Ishihara test. This seems to be an area deserving of further research.

Career Guidance

It is evident from comments made that some specialists in community medicine responsible for child health have little knowledge of defective colour vision in general and the possible career implications, and do not keep up-to-date with modern methods of diagnosing colour vision anomalies. Furthermore it is clear that some confusion exists over the question of whose responsibility it is to provide career guidance for colour defective children. The responses made on the questionnaires indicate that many child health specialists do not consider it to be their responsibility - perhaps justifiably. Usually the parent or teacher is informed when a colour vision defect is discovered in a child. In over seventy percent of cases the teacher is acquainted with the facts. One quthority made a point of informing science teachers - presumably to avoid possible trouble with chemical analysis. In fifty-eight authorities the parents are informed of the defect and thirteen authorities inform the child directly. The present author feels that both the teacher and parents should be informed, and in cases where the child is of an age to understand without undue anxiety, he also should be told. The considerable distress and anxiety that can be caused to the parents of a child who has been labelled "colour blind", as indeed to the child himself, was mentioned by one specialist in child health. This can be overcome considerably by education with the true facts. Several authorities send an explanatory letter to the parents of children who have failed the school colour visions test, pointing out that defective colour vision is a common occurrence, and that the anomaly will probably not present any severe handicap during life, but indicating that a severe defect may restrict the choice of career slightly. Five authorities mentioned that this was their usual procedure and enclosed a copy of the standard letter used. Examples of these letters, some of which are to be commended for their approach, are given in Appendix 11 .

In general there is good liaison between the careers Advisory Service and/or the Employment Medical Advisory Service (E.M.A.S.). Many examples of this arrangement were mentioned in the questionnaires. It appears that Careers Officers are mainly responsible for giving advice to colour defective school leavers. The following comments are of interest:

> "Career guidance is available through the careers Advisory Service who if necessary consult with E.M.A.S."
>
> "All Careers Officers are aware of the problems of colour blind school leavers and give them appropriate advice."

Some authorities were not so concerned and did not know what facilities were available.

One authority mentioned that when the occasional case of defective colour vision is diagnosed it is "almost always" in children who do not intend to embark on careers in which colour vision is important. This was endorsed by another who said that he had come across "only a handful of children whose career and colour vision were incompatible." It is possible that some parents of children with severe colour vision defects, or the children themselves, are aware of their handicap from an early age, and they deliberately avoid plans for, or thoughts of, a career involving colour identification. This is not usually the case, however, and one authority had realised that giving the Ishihara test to "the leaver group" was too late to be of help in many cases. TAYLOR (1966) confirmed this view. He found that more than half the colour defective children he saw had chosen unsuitable careers involving colour judgement.

In the industrial context it is the responsibility of the Employment Medical Advisory Service (E.M.A.S.) to advise on the suitability of a known colour defective individual for a job involving colour discrimination. The form Y9 is quite frequently used to indicate the presence of a colour vision defect; twenty-eight percent of authorities use this method of notification. Since 1972 it has been the responsibility of the School Medical Officer to pass on the information to the appropriate channel. In general, the Careers Officer of the Department of Employment receives the form Y9 and the information is sent to E.M.A.S.[1] The employer may notify the employment exchange that a colour defective individual has been employed, if he feels this is appropriate. E.M.A.S. will then advise in particular cases.

It is pleasing to find that some child health specialists take the daily problems of colour defective children, and their career guidance, very seriously. One authority[2] mentioned that a peripatetic teacher of the visually handicapped had recently been appointed and would help in this field. A comment made by the same authority on the need for career advice effectively summarises the whole situation and reveals the inadequacy of the present arrangement.

> "One of our principal difficulties is the sort of advice to give to parents and children upon discovering a degree of defective colour vision, as the effect of the handicap in industry is generally hard to assess.

1. Personal Oral Communication with Dr. D. Smith, Birmingham E.M.A.S. November 1973

2. Liverpool

The Armed Forces and Railway appear to have their own standards and are prepared to carry out testing on prospective recruits."

Recommendations

It is clear that more sophisticated methods of diagnosing defective colour vision must be introduced into the school medical examination if sensible career guidance is to be given. It is well-known that the Ishihara test can only serve as a screening test with any degree of reliability, to separate colour normal form colour defective individuals, BELCHER, GREENSHIELDS AND WRIGHT (1958). As TAYLOR (1956) has pointed out, further efforts must be made to grade the defect using other tests, if useful and appropriate advice is required. Separating the "safe" from the "unsafe" is one approach. For instance, one authority admitted that they did not give any career guidance at present, but they hoped to do better and were acquiring an Edridge-Green lantern to sort out the safe defectives from those who have serious defects. Another illuminating comment along the same lines, obviously prompted by experience, suggested:

> "More discriminating tests are required and more specific information regarding occupations which can be carried out with different degrees of defective colour vision."

In addition it should be the ultimate responsibility of the individaul industrial employer to make a realistic assessment of a recruit's capabilities for colour work based on the particular requirements of the industry. This view was expressed by one authority who considered that the employer should check the colour vision of recruits to see if the specific job presented problems.

It is plainly clear that specialists in child health are seldom in a position to predict the possible career limitations in individual cases solely on the basis of the Ishihara test. Very often they are even uncertain as to when to refer individuals for an additional colour vision examination, as one specialist explained. If advice is given by the Careers Advisory Service on the basis of information provided from school colour vision examinations, as is generally the case, the situation is little improved. What is needed is a system of referral formore exhaustive clinical tests, possibly coupled with a practical assessment of colour ability, and a sympathetic interpretation by a person with experience. An intelligent medical auxillary or nurse, or a Careers Officer, might well be able to cope with this role.[1]

1. The Kirklees Area Health Authority in Huddersfield have recently reorganised their policy after discussions with the local officer of E.M.A.S. They decided that the school nurse should be trained to use a colour matching test such as matching wools or wires, for boys at the age of eight and if a child fails, a notice would be sent to both the parents and the school to point out that the child has a significant defect of oolour vision which might affect the suitability for certain employment later. The parents and teaching staff are encouraged to contact the child specialist if the questinn of a career in which accurate colour vision is required, arises.

Furthermore if the recommendations (given later) which result from this study are heeded a more realistic and helpful approach to the problem of career guidance for colour defective children will follow.

TABLE 63

Results of questionnaire to Area Health Authorities in England (Specialists in Community Medicine Child Health)

No.	Question	Percentage %
1.	Is Test given	
	Test given	100
	Test not given	0
1a.	Test used:	
	Ishihara	92*
	Keystone	31
	Guys	5
	Other	4
1b.	Age of first test	
	4-6 years	14
	7-9 years	14
	10-12 years	64
	13-15 years	8
	Repetition of Test	
	After 3 years	2
	4-5 years	5
	6 years	6
	7-8 years	1
1c.	Administered by:	
	Medical Officer	38#
	Nurse	76
	Technician	8
1d.	Test given to:	
	Boys and Girls	69
	Boys only	31
Ie.	Action taken: ø	
	Further test	7
	Referred to ophthalmologist	3
	Parents informed	58
	Teacher informed	31
	Child told	13
	Noted on Form Y9	28
	Noted on School Medical Record	6
	G.P. informed	2

* Includes 31% keystone

\# In 21 cases Medical Officer and Nurse administered test

ø Sometimes multiple action taken

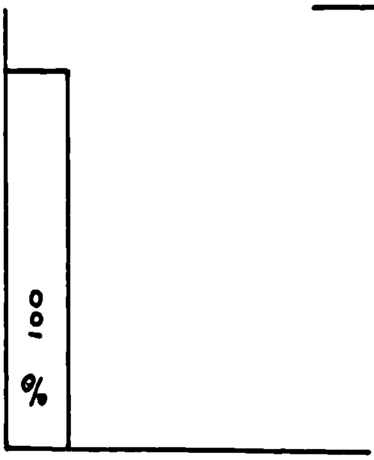
No.	Question	Percentage %
2	Career Guidance given:	
	General	39
	Youth Employment Service	33
	Teacher informed only	5
	Others	3
3.	Teacher informed	
	Yes	71
	No	12
	Sometimes	1
4.	Choice of test:	
	Historical	32
	Experienne/best test	24
	Central advice	3
	Local advice	7
	Advicefrom ophthalmologist	2

Total number of replies = 101

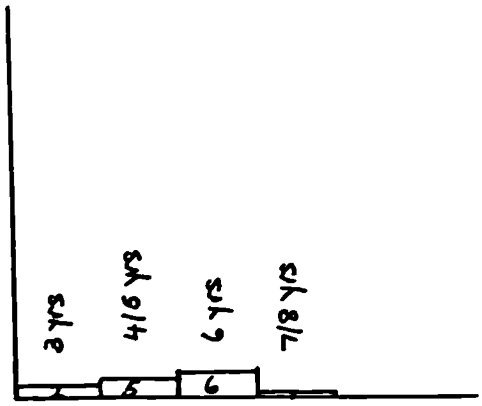
Percentages do not always add to one hundred because of incomplete information given and some overlap.

COLOUR VISION TESTING IN SCHOOLS

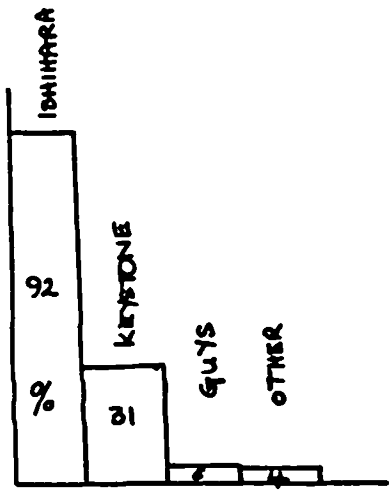
Fig 68



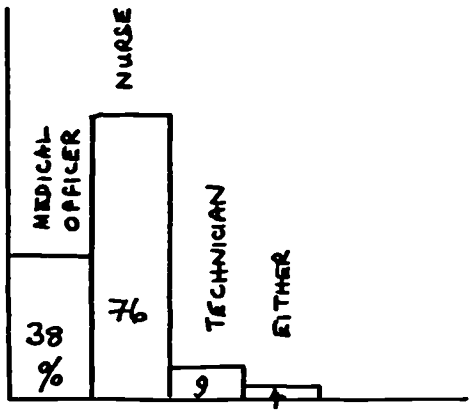
1. Is test given?



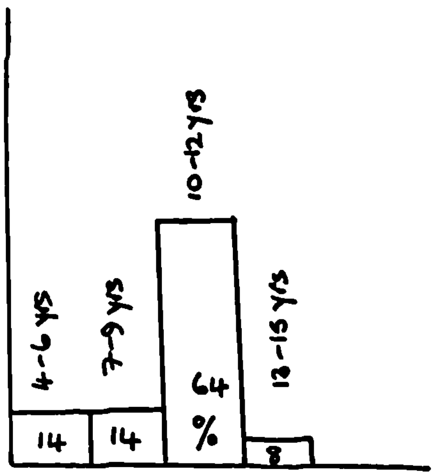
1b. Repetition of testing



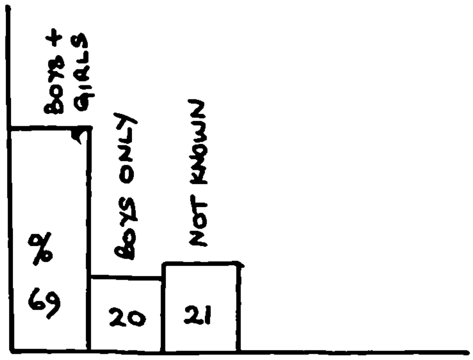
1a. Test used



1c. Test administered by;

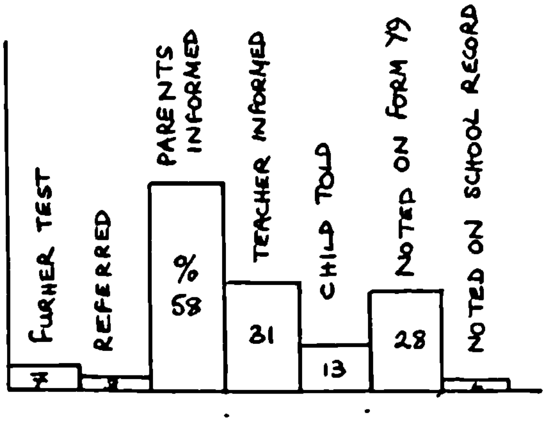


1b. Age of Testing

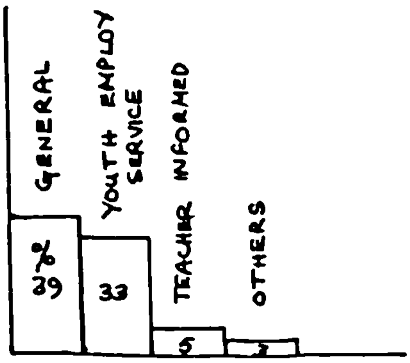


1d. Test given to;

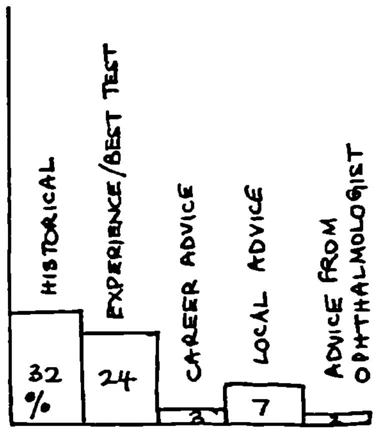
COLOUR VISION TESTING IN SCHOOLS



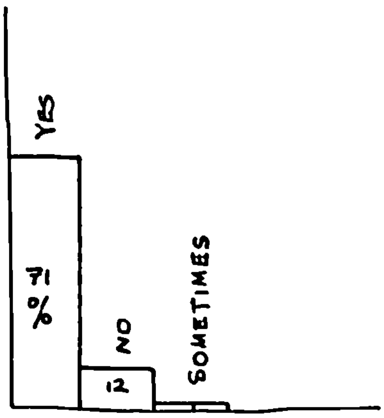
1e. Action taken



2. Career guidance given



4. choice of test



3. Teacher informed

VI 2 Colour vision testing in higher education establishments concerned with colour.

Since normal colour vision is required in many industries involved with colour, it is appropriate that entrants to courses of higher education, which provide graduates for these industries, should be screened for defective colour vision. Such action would prevent the obvious distress and disappointment that arises when a newly qualified graduate is rejected from employment in his chosen field because of defective colour vision.

Cases involving textile and colour chemists have arisen. Details of two such individuals were passed to the present writer by the Courtaulds Research Laboratory, Manchester. In one case the man involved had taken a degree in the Department of Textile Industries at the University of Leeds. He had applied to Courtaulds for a post and indicated on the application form possible red/green colour blindness. In a letter from Courtaulds it was pointed out that in view of the nature of the work, only staff with good colour vision are usually employed, and a suggestion was made that a colour vision test should be conducted by the Department of Colour Chemistry at the University of Leeds. A report was requested. The student was found to have "a marked degree of red/green defective vision" on the Ishihara test and had little option but to withdraw his application from that department. He asked for the application to be redirected to another division where normal colour vision was less important. Another case involved a chemistry graduate of the University of Strathclyde who was planning a career on the dyeing and finishing side of textiles. He was given the Ishihara test at the Courtaulds interview and was surprised to be classified as "strongly red/green defective". As a result he was rejected from employment with the company. The Courtaulds interviewer wrote to his University tutor explaining the situation and pointed out that in view of his colour vision defect the student was unlikely to be able to enter the dyeing side of the industry. A suggestion was made that a colour vision check should be /given to students entering the department, or at least those who appar to be orientating themselves towards a career in the colour-making or colour-using industries, to prepare them for routine colour vision testing in industry. It was also emphasised that such a policy would facilitate a more sensible discussion on career prospects at the initial interviews with employers in the University. The tutor replied indicating that he had made arrangements with the University Medical Officer for colour vision testing to be available on request. He expressed deep regret at the refusal of the colour defective applicant, and recalled that during his own industrial employment when a sudden decision was made to test for defective colour vision, several technical people who had "spent a lifetime judging colours" were found to be colour-blind.

A brief note explaining the company policy towards colour vision defects is now issued to individuals who make an application to Courtaulds Dyeing Research Laboratory.

Investigations were made among selected University departments who were known to run courses on colour subjects. The policies adopted by the individual departments are given below:

Educational Establishments

University of Leeds
Department of Colour Chemistry and Dyeing

Colour vision testing of undergraduate students enrolling on courses has been the practice since 1939. Applicants for places on the course are not tested, only those who actually start on the course. More recently post-graduate students have also been tested. No bar is made if a student is found to be colour defective - it is just felt to be important that he should be aware of possible difficulties.

The Polytechnic, Huddersfield.

Students entering designing or dyeing courses are tested for colour vision during the first week of the course. In future testing will be at the time of interview for entry to the course.

University of Bradford

Postgraduate school of studies in Colour Chemistry and Technology

All students on courses are tested with the Ishihara test. Any colour defective students are referred to the Ophthalmic Optics department for testing with the F-M 100 Hue test.

Cambridge College of Art and Technology

School of Art

All printing students are given the Ishihara test by the college nurse. The extension of this policy to student applicants is under consideration.

VI 3 Occupations, jobs and careers which are likely to cause difficulties for colour defective observers

Attempts have been made to list the occupations, jobs and careers which are likely to cause difficulties for colour defective observers.

In his book 'A Guide to Occupational and Other Visual Needs' HOLMES (1958) describes numerous jobs and occupations which rely upon the correct identification of colours, or perfect colour discrimination. JAENSCH AND KAISER (1958) in their book (in German) 'Eye and Choice of Profession', list occupations in both the armed services and civilian life with their necessary visual requirements, including colour vision. In neither these studies are sections devoted specifically to colour vision, so that the reader must peruse all occupations described to find the colour vision requirement. The Youth Employment Service issued a two-page leaflet in 1966 on "Careers and Colour Vision" as part of their Careers Bulletin. After a brief introduction, skeleton lists are given of careers in which defective colour vision is a bar to entry and careers and occupations where defective colour vision may be a handicap. The latter list contained only eighteen jobs and it is far from exhaustive, but for several years this was the only document offering guidelines for those involved in career advice. The Employment Medical Advisory Service (E.M.A.S.) revised form adding one or two more occupations to the list.

TAYLOR (1971) has attempted to divide lists of careers and occupations into:

1. Occupations in which colour defect is a minor handicap
2. Occupations in which colour defect is a major handicap

These divisions are based on the career choices made by eight hundred andthirty-one patients seen in the advisory clinic for colour defective children and the recommendations of the Careers Bulletin of the Youth Employment Service. STRUTHERS, (1971) working with Taylor, made her own survey of nineteen industrial establishments in Ayr shire concerned with colour, and identified eighteen areas requiring careful consideration regarding colour vision.

The Civil Service has produced a list of the grades within their operations which require satisfactory colour vision.

An attempt has been made by the present author to use all these sources, together with information collected during this study, in an effort to produce as complete a list as is possible. The list is not in any way exhaustive; the sheer magnitude of the task and the development of new jobs from time to time makes this an impossible task. In some cases jobs can fall into several categories. A separate list of jobs and ranks within the Armed Forces which require good colour vision is given in Appendix 2 .

/ • <u>Careers/Jobs/Occupations where good colour vision is desirable, but defective colour vision would not necessarily cause a handicap.</u>

Accountant
Anaethetist
Architect
Artist - graphic, commercial, advertising
Auctioneer

Barmaid/Barman
Bacteriologist
Baker
Beautician
Botanist
Brewer
Butcher
Builder/Brick Layer
Buyer - textiles, yarn, tobacco, food e.g. fruit, cocoa, timber

Carpenter
Carpet/lino fitter/planner
Chiropodist
Clothes designer
Cook or chef
Coroner
Confectioner
Cosmetics director (stage, film, T.V.)
Curator (museum)

Dental surgeon and technician
Draughtsman
Dressmaker
Driver Instructor
Driver in public services e.g. bus

Engineer (various)

Farmer
Fishmonger
Florist
Forester
Furrier

Gardener and landscape gardener
Geologist
Gemologist e.g. setting stones, diamond grader
Grocer

Hairdresser
Horticulturlist

Illuminating engineer
Interior decorator/designer/planner

Jeweller

Librarian
Lighting director (stage, film, T.V.)

Manicurist
Metallurgist
Milliner
Miner

Nurse

Optometrist/ophthalmologist
Osteopath

Painter
Pharmacist assistant (counter service)
Physician
Physiotherapist
Post Office counter assistant
Potter

Salesman/woman (fabrics, drapery, yarns, wool, carpets)
garments/footwear
china and glass
linen
cosmetics/toiletries
jewellery
confectioner
stationer
storekeeper

shoe repairer
surgeon

Tanner
Tailor
Telephone switchboard operator
Theatre/stage props manager

Veterinary surgeon

Waiter
Window dresser

Zoologist.

Careers/Jobs/Occupations/Industries where defective colour vision is a handicap and important consequences might result from errors of colour judgement

Air traffic controller

Buyers - textile, yarns, tobacco, food e.g. fruit, cocoa, timber

Car body resprayer, retoucher
cartographer
Ceramics - painter/decorator of pottery
inspector (quality control)
Chemist and chemicals - laboratory analysis
food chemist
teacher of chemistry
manufacturer of chemicals and polishes and oils.
Colour printer, etcher, retoucher
Colour photographer
Colour T.V. technician
Coloured pencils/chalks/paints manufacturing
Colourist/colour matcher in paints, paper, pigments, inks, dyes, wallpaper.
Cotton grader
Coroner

Forensic Scientist

Market Gardener e.g. fruit
Meat inspector

Oil refining

Paper making
Pharmacist
Plastics
Paint maker and distributer

Restorer of paintings/works of art

Safety officer

Tanner
Tobacco grader

Careers/Jobs/Occupations/Industries requiring perfect Colour Vision.

Armed forces - certain grades (see separate list)

Civil Aviation
Colour-matcher in dyeing, textiles, paints, inks, coloured paper, ceramics, cosmetics
Carpet darner/inspector, spinner, weaver, bobbin winder

Electrical work - electrician
electronics technician
colour T.V. mechanic
motor mechanic
telephone installer

Navigation - pilot, fisherman, railways

Police - certain grades

Radio - telegraphy

Occupations/activities where defective colour vision may be an asset

Camouflage detection

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

It has been shown repeatedly in this study that there is an almost universal dependance upon visual colour judgement and assessment even in those industries where objective methods are sometimes used (e.g. textiles and paper-making). These findings confirm those obtained in 1946, although this is surprising in view of the advances in colorimetric technology and computer interfacing that have been introduced during the last quarter-century.

The investigations indicate a distinct improvement since 1946 in the extent of routine colour vision screening in industry; however, the types of tests used today are virtually unchanged, and in only a small proportion of cases is care taken to use a suitable illuminant with the tests. The Ishihara test is used almost universally, and there is considerable ignorance of the alternative testing methods which are available. Widespread dissatisfaction was reported with the tests in circulati n at present. Users frequently reported that the Ishihara plates were too severe for their purposes, and that many who fail it could adequately cope with a colour job. JOLLY (1954) and JORDINSON 1959 showed this earlier, but comments made to the present writer by industrial medical offices (section.3.2) and personal observations, amply confirm this view. Very few industrialists involved with colour testing (medical, personnel or technical) were aware of the existence of acquired colour vision defects – the disturbances in colour vision which are frequently associated with medication, trauma, or certain pathological conditions. Accordingly most testers were unaware of the importance of screening for tritan defects, particularly in older people. Testing was almost always confined to the preëmployment stage with no opportunity for re-testing later in life; The Railways were one of the few exceptions. In only a few of the companies contacted was the deterioration of colour discrimination ability with age recognised. But even in these cases the knowledge was seldom put to any useful purpose.

The literature suggests that some colour defective observers may be capable of some industrial colour jobs. It is gratifying to be able to substantiate this view on the basis of evidence obtained from the personal study of many industrial colour jobs and the testimony of the few colour defectives and their colleagues who have been encountered in these industries. The performance of colour defective observers at simulated colour tasks in the laboratory reinforces the view that mild anomalous individuals are capable of some colourorientated occupations. Furthermore, it has been shown that where there is a brightness difference between two colour samples, many colour defectives achieve a record of colour judgement and identification comparable to that of colour normals. In particular, the ad ption of this recommendation for colour codes will greatly increase the clarity for colour defectives.

An attempt has been made to produce a comprehensive list of jobs and occupati ns which are likely to cause difficulties to colour defective people and to divide them into appropriate categories. It is now possible to reinforce with substantial new evidence that decisions concerning the suitability of mild colour defectives to carry out colour orientated jobs in industry should be made with great care, taking all factors into account, but frequently erring in favour of retaining the individual in his work unless questions of safety are involved. As a result of this it can be stressed that the categories presented cannot be completely ri gid. Although differences in interpretation must inevitably persist, the many examples which the investigation has revealed will give useful guidance. Individual assessment is essential, and it has been established beyond doubt that it is unwise to make generalisations concerning the capability of a given person performing a certain job.

The need for a realistic approach to the examination of colour vision in industry and in situations where the career guidance of a colour defective child is in question, has been stressed.

In particular, the need to diagnose the severity of the defect has been emphasised throughout. To achieve this end a radical change must take place in the testing methods used in industry. The Isihara test, used alone, is not adequate as an indicator of the ability or suitability of a colour defective individual to work in colour industries. Only in those situations where the colour vision requirements are exceptionally strict can its use be justified. No single colour vision test can claim to be infallable for such a purpose; the use of two or three tests is recommended, and where possible and appropriate a trade test should be included.

It is perhaps unfortunate that the results of this study suggest that no single c l ur visi n test is ideal as an indicator of potential industrial performance. For this reason the use of trade tests seems appropriate.

There are several readily available clinical diagnostic tests which are capable of serving the industrial need more adequately than a simple screening test. The Farnsworth dichotomous D IS test has a number of attractive features for this purpose. It is easy and quick to use and interpret by a relativly inexperienced examiner and is low in cost. Furthermore it was designed to separate the "safe" from the "unsafe" defective when the need for such a test arose during the second World War. It fails only the five per cent of men who have a significant defect; the remaining three per cent of colour anomals who show only slight defects, pass without much difficulty. A suitable alternative, with a number of additional features appropriate to the industrial context (e.g. format and the provision of a record sheet) is The City University Test which also uses Standard Munsell colours. The Lovibond Colour Vision Analyser has been shown by DAIN (1971) to separate the extreme anomalous subjects from those mildly affected with a considerable degree of accuracy and reliability.

This test can also claim potential for industrial use. It is essential for fair selection that the pass-fail criterion for each test should be set with the needs of each particular occupation considered, bearing in mind that a given industry may include a range of occupations. There is a strong case for a test which can be altered in its severity as in the Lovibond Colour Vision Analyser and the H.R.R. Plates (the latter are unortunately now out of print). More vigilance must be extended to the detection of acquired defects in industry; the tests recommended* are also suitable for this purpose. In addition, it is important to realise that a colour vision test is not a test unless it is used with an appr priate illuminant.

A final c nsiderati n of major importance, concerns the question which can be simply stated" Whose responsibility?" It is perhaps disquietening to realise that this investigation fully endorses an original suspicion that the responsibility to examine the colour discrimination capabilities f prospective industrial employees or recurits, and make decisions accordingly, is taken lightly in many cases. Confusion frequently surrounds the matter, in particular of whose responsibility it is to make decisions and give advice. This has been shown especially in the printing industry. Trade Research Associations, Industry Training Boards and Trade Unions all have a responsibility to make the situation clear within their particular industry and to issue practical guidelines and recommendations which individual companies can follow. The Employment Medical Advisory Service and the Ophthalmic Services must be in a position to offer assistance and advice when approached. The Ophthalmic optician in particular must be prepared to examine colour vision as part of his routine eye examination and give appropriate consultation. Individual companies must realise that the responsibility ultimately falls upon their shoulders for they have the job of selecting their own employees. Recommending bodies such as the British Standards Institution (B.S.I.) Should be encouraged to consider the problems of the colour defective in matters such as colour coding.

* ie. the Farnsworth D15 test and the Lovibond Colour Vision Analyser

Colour vision testing and advice is no easy matter. All too often the decision on whether to accept or reject a candidate who has a colour vision defect, falls to inexperienced lay personnel. Discussion and the opportunity to gain experience in both testing and evaluation of capabilities for occupational purposes is vitally important. It is therefore recommended that personnel concerned with selection and placement should be encouraged to draw upon the experience and expertise of specialists. In addition, they should be encouraged to attend courses designed to educate and train in this field. There is a need for better literature to inform and educate the general public and the medical profession about colour vision deficiencies and the associated industrial and occupational consequences; consultancy facilities are also needed. Perhaps above all this study has demonstrated that there exists a great need for practical advice and help throughout all sectors of industry. Where industry is ready to listen those who have the knowledge must be ready to advise.

APPENDIX 1

A Selection of Colour Codes used for Industrial Purposes

Abbreviations

R	Red	P	Purple
O	Orange	M	Mauve
A	Amber	W	White
Y	Yellow	g	Grey
G	Green	b	black
T	Turquoise	pi	pink
B	Blue	Cr	cream
V	Violet	br	brown

B.S. 381C (1964) colours for specific purposes.

Contents of gas cylinders

B.S. 349 (1973) Identification of the contents of industrial gas containers

Maroon, French grey, Peacock blue, Signal Red, Golden Yellow, Dark Violet, Middle Brown, Light Brunswick Green (colours of B.S. 381C)

B.S. Medical gas cylinders and anaesthetic apparatus

W,B,O,g,V,br,b.

IS O/R 32 - (1957) Identification of the contents of medical gas cylinders

W,B,O,g,V,br,b. Chromaticity values specified

IS O/R 443 - (1965) Marking of aircraft gas cylinders W,O,b.

Contents of fire extinguishers

B.S.DD 48 (1976) Identification of fire extinguishers

R,Cr,B,b,G.

Contents of Pipelines

B.S. 1710 (1975) Identification of pipelines

G, Silver Grey, br, Yellow-ochre, V, Light blue, b, O,R,Y, Auxilliary blue, Crimson, Emerald green, Salmon pink, Y, W, terracotta, primrose, French blue, French grey.

B.S. M23 (1968) An identification scheme for pipelines

B,G,Y,br,O,R,g,b,W.

ISO/R 12 - (197) Identification of aircraft pipelines

B,G,Y,br,O,R,g,b. Chromaticity values specified

ISO/R 508 - (1966) Identification colours for pipes conveying fluids in liquid or gaseous condition in land installations and on board ships,

G, Silver Grey, br, Yellow-ochre, V, Light blue, b,W, Safety red, safety yellow, auxillary blue. Chromaticity regions specified.

Pressure Ratings

B.S. 4159 (1967) Colour markings of plastic pipes to indicate pressure ratings.

W,Y,R,B,G,br.

Capacities of pipettes

B.S. 3996 (1966) colour coding for one-mark and graduated pipettes.

b,W,Y,O,R,G,B

ISO 1769 - (1975) Laboratory glassware (pipettes) colour coding

B,R,Y,G,W,O,b.

Controls and states of equipment

B.S. 4099 (1974) colours and their meanings when used for indicator lights, annunciators, and digital readouts for industrial purposes.

R,G,W,B,O

Anticoagulants

B.S. 4851 (1972) Medical specimen containers for haematology and biochemistry

pi,B,M,Y,G,O,br.

Values of resistors and capacitors

B.S. 1852 (1975) Marking codes for resistors and capacitors

Silver, Gold, b, br, R,O,Y,G,B,V,g,W.

Electric cables and wires

B.S. 1843 (1952) Colour code for twin compensating cables for thermocouples

R,Y,G,B,br

B.S. 3858 (1965) Binding and identification sleeves for use on electric cables and wires

pi,b,br,R,O,Y,G,B,V,g,W,B-b.

B.S. 4410 (1969) The connection of flexible cables and cords to appliances

G/Y, br, B

B.S. 6004 (1975) PVC-insulated cables (non-armoured) for electric power and lighting

G/Y,B,R,b,Y,g,W.

B.S. 6007 (1975) Rubber-insulated cables for electric power and lighting b,G/Y,B,R,br,Y

B.S. 6500 (1975) Insulated flexible cords

G/Y,B,br,b,Y,R.

B.S. 6746 (1969) PVC insulation and sheath of electric cables

B,br,b,cr,g,G,O,pi,R,T,V,W,Y.

B.S. AU 7 (1968) Chart and colour code for vehicle wiring

br,B,R,P,G, Light Green, W,Y,b,O,pi, slate

B.S. PD 2379 (1962) Register of colours of manufacturers' identification threads for electric cables and cords

b,B,br,G,g,M,O,P,R,W,Y.

<u>Current ratings of fuses</u>

B.S. 646 (1958) Cartridge fuse-links for a.c. and d.c.

G,Y,B,R.

B.S. 1361 (1971) Cartridge fuses for a.c. circuits in domestic and similar premises

W,B,Y,R,G.

B.S. 1362 (1973) General purpose fuse links for domestic and similar purposes (primarily for use in plugs)

R,br,b.

B.S. 2950 (1958) Cartridge fuse-links for telecommunication and light electrical apparatus

Salmon pink, dark Admiralty grey, Post Office red, Dark brown, Golden yellow, Mid Brunswick green, azure blue, sky blue, dark violet, W, light orange.

Safety advice

B.S. 2929 (1957) Safety colours for use in industry

R, O-Y,G,b,W

B.S. 4218 (1967) Self-luminous exit signs

ISO/R 408 - (1964) safety colours

R,Y,G,B,W,b Chromaticity regions specified.

B.S. M 44 (1974) Identification of aircraft servicing, maintenance, ground handling and safety/hazard points.

b,W,Y,R, Fluorescent R.

Others

Pharmaceutical products/medicines/chemical analysis of body fluids e.g. Urine testing, insulin

Filing systems used in libraries, banks, and general offices.

APPENDIX 2

Official Colour Vision Requirements for Armed Services and Public Bodies

The Armed Services and Public Bodies concerned with transport (e.g. British Railways) have been aware of the need for colour vision standards for many years. The history surrounding the introduction of official colour vision requirements for the Armed Services makes fascinating reading, and it is perhaps surprising to discover that the subject has even been considered by both Houses of Parliament in 1912, and before that by a committee of the Royal Society in 1892. TOOLEY (1959) has ably summarised the history of colour vision testing and the introduction of standards for the Merchant Navy. The colour vision requirements of the Royal Navy were studied at the request of the Admiralty in the early 1930's and a special report on the subject was published by the Medical Research Council in 1933. Colour vision standards within the National and Public Services were briefly considered by the Committee of the Colour Group (G.B.) responsible for the report on defective colour vision in industry in 1946. More recently the subject came up for discussion at a meeting of the Royal Society of Medicine (Opthalmology and Occupational Medicine sections) held in London in February 1975.

Colour identification within the Armed Services and transport areas is mainly concerned with the recognition of certain colours used in signals, and the problems are therefore rather different from the general industrial situation where colour matching or appraisal is the main concern. A major survey of this aspect is considered to be outside the strict scope of a study concerned with industrial aspects of defective colour vision, and for this reason only brief descriptions of requirements within the Armed Services and Public corporations are given.

1. TRANSPORT

The first tests for defective colour vision were based on the matching of coloured wools or beads. Holmgren was responsible for producing his wool test as a result of a major train crash in Sweden in [illegible] and it became popular for use among railway employees in Europe and the USA until the early twentieth century.

British Rail

All persons who apply to join the staff of British Rail are given a colour vision test and the result is recorded. An estimated total of 200,000 people throughout the U.K. are required to satisfy the colour vision standards.

Tests used:	Ishihara test Edridge-Green lantern (identification of red, green, yellow and white lights)
Given by:	Doctor/Nurse/Technician

Persons who must pass colour vision test

Footplate-men (drivers), driver's assistants and trainees, operators, some supervisors in traffic section, signalmen, guards, shunters, patrolmen, track maintenance staff and those concerned with electrical wiring.

All drivers, operators and some supervisors in the traffic section have a periodic reassessment of colour vision. The frequency is usually at five-yearly intervals until the age of 60 and at two-yearly intervals thereafter.

Although there is no record of a major operating accident having resulted or been said to have arisen from defective colour vision, mistakes due to colour anomalies have been reported; these involved passing a red signal and mistaking coloured signals.

London Transport

All persons who apply to join the staff of London Transport are given a colour vision test on entry and the result is recorded. Most persons who fail the colour vision test are refused employment except for graduates who go into railway or signalling jobs, and in this case their supervisors are advised of their disability. There are over 9,000 motormen and 2,000 guards employed by London Transport.

Tests used: Ishihara test - a candidate can be refused employment for failing one plate.

Edridge-Green lantern with two apertures, 3 colours and filter to simulate rain and fog.

Given by: Doctor

The present tests have been used since the 1940's. Until 1932 the Holmgren wool test was used.

Persons who must pass colour vision test

Drivers, signal engineers, signalling staff, shunters, guards and certain track workers.

All drivers and operators concerned with moving stock are re-examined with the lantern test at age 50,55,60,63.

Two cases of acquired colour vision defects resulting from tabacco amblyopia have been reported.

Colour vision testing was introduced in the mid 1930's for bus drivers when coloured traffic signals were introduced. A study made in 1960 by Dr Norman on medical aspects of road safety, in which he studied one hundred and fifty colour defective bus drivers who were driving buses and a control group, proved that there was little difference in performance between the two groups. As a result of this study, the colour vision requirement for bus drivers was dropped.

Trains have an automatic stopping mechanism for red signals on the tracks, but not in sidings. No accidents or incidents reported in the last twenty-five years has been attributed to defective colour vision although an accident on the Circle line in 1938 was said to have been caused by the incorrect wiring of signals.

Road Transport

There are no restrictions on colour defectives from holding a licence to drive a private car, goods vehicle, heavy goods vehicle or public service vehicle in this country. In Austria and Hungary protanopes and achromats are denied private car licence, and are excluded from driving taxis, buses and lorries in Austria. In Canada, Sweden and Hungary, bus drivers must have normal colour vision.

2 AVIATION

Royal Air Force

A letter from the Consultant Adviser in Ophthalmology[1] suggests that defective colour vision is a bar to entry to certain branches and trades of the R.A.F. The Force are only concerned whether colour perception is normal or abnormal and are not concerned with the type of defect. Three classifications are applied on the basis of the Ishihara test and a Lantern test, (Martin lantern or Giles-Archer)

1. Letter from Air Commodore T. Price to Mrs. J. Popplett 10th May 1974

1. Colour normal

2. Colour defective safe

3. Colour defective unsafe

Tests used:

The Ishihara test is given under daylight or an approved illuminant. Those who fail are given a trade lantern test (Martin lantern or Giles-Archer) in which the colours red, green and white must be correctly identified at low luminance levels and small angular subtence. Those who make no errors are classified as "colour defective safe" those who make errors are classified as "colour defective unsafe". The correct recognition of colours used in certain trade situations as assessed by simple tests with coloured wires, resistors etc. is applied in some cases.

Persons who must pass colour vision test

Colour normal requirement electrical, electronic, marine, safety, photographic, explosive personnel.

Colour defective safe Aircrew, general engineering staff, driving, air traffic control, firemen, gunners, police.

Civil Aviation

Applicants to the civil aviation authority must "demonstrate their ability to perceive readily those colours the perception of which is necessary for the safe performance of duties".

Tests used:

Ishihara plates illuminated by illuminant C or D. A candidate who fails can be assessed as fit provided he passes the colour lantern test (Martin or Giles-Archer lantern).

Persons who must pass colour vision test

Flying personnel - air-line transport pilot
flight navigator
flight engineer
radio officer

Air traffic controllers

Private pilots

Most engineering apprentices.

In the 1946 Report on Defective Colour Vision in Industry it is noted that defective colour vision is not necessarily a bar to safe flying and if the applicant for a private licence is able to distinguish the coloured lights used in air navigation, he may be awarded a licence for day and night flying. If he fails to identify correctly the coloured lights his licence is endorsed, and he is restricted to flying only between sunrise and sunset. Those applying for a private licence or as engineers must possess normal colour vision, although certain anomalous trichromats may be accepted. A number of recent studies, AGARD report (1972), HOOGERHEIDE (1959) on this aspect, suggest that some anomalous trichromats can be considered safe for flying duties.

3. MARITIME

Merchant Navy

History A variety of tests have been used in the Merchant Navy over the years. TOPLEY(1959) notes that before 1845 anyone could sail as a master or mate and no visual standards were applied. In 1877 a primitive form of colour vision test was introduced using coloured glasses and cards. Candidates had to distinguish the principal colours, but there was no uniform method of testing. Soon after one of the examiners reported to the Board of Trade that a candidate who could not name the coloured glasses correctly in daylight made no mistakes if they were displayed in front of an oil lamp flame. This led to the introduction in 1885 of an oil lamp which was supplied with a removeable ground glass screen for use with an improved set of coloured glasses and cards. In 1892 a committee of the Royal Society under the chairman of Lord Rayleigh recommended that the card and glass test should be discontinued in favour of Holmgren's wool test. This method was still far from satisfactory, however, as the famous case of Mr. Trattles indicates. Trattles had been at sea for several years and became a second mate in 1902 passing the Board of Trade colour test. When examined a year later, as part of the test for first mate, he failed

the Holmgren wool test and a later appeal test which included a lantern. He was asked to surrender his ticket. The gentleman persisted and between 1904 and 1907 he was examined six times (three of which he failed and three he passed) and also by Sir William Abney, ophthalmological adviser to the Board of Trade, and Dr. Edridge-Green. Both men produced evidence where one would have passed Trattles and the other failed him. The Board of Trade was severely criticised and it suffered a great deal of adverse publicity. The Holmgren wool test was discontinued and the Board of Trade lantern was introduced in 1913 as a fairer test of practical ability at sea. The case indicates the extreme difficulty which sometimes arises in placing an individual on the proper side of the safety line. The need for standard viewing conditions and a universal technique or procedure associated with the testing of colour vision, is also indicated. At the February 1975 meeting of the Royal Society of Medicine on Visual Standards it was pointed out that the luminous intensity of the Board of Trade lantern and the Martin lantern is so near the colour threshold value that the test presents some difficulty to a number of colour normal people. The need for a colour vision standard to be based on "reasoned principle and applied with a due sense of proportion" was stressed.* The introduction of the Wright-Holmes lantern to replace the Board of Trade lantern may help in future.
A very recent case which reinforces this point came to the notice of the present writer. A young man who had passed

* By Captain Barras

the examination for a yacht master's (ocean) certificate was not awarded the certificate because he had failed the Board of Trade colour lantern. He attended the City University for a second colour vision test at the recommendation of his ophthalmic optician, and was found to be virtually perfect on the Ishihara plates and the H.R.R. plates and perfect at the D.15 test. In the first box of the F-M 100 Hue test, he made five minor transpositions, all other boxes being perfect. On the Giles-Archer standard lantern, the more difficult of the two lanterns, he had slight difficulty with the green aperture on the very small aperture with the neutral density filter and the dark red, but many colour normals have this difficulty.

Royal Navy

History A special MRC Report on Colour Vision Requirements in the Royal Navy was published in 1933 (Report No 185) at the request of the Admiralty. At that time the regulations stated that persons entering all branches of the Navy should have normal colour vision and re-examination at training establishments was forbidden. The system had proved to be unsatisfactory, however, because between 1929 and 1933 ninety-three seamen had been invalidated because they had a "dangerous" colour vision defect. Others who had been accepted as colour normals by recruiters or civil medical examination were rejected at their final medical examination on account of defective colour vision.

The authors considered it to be "irrational" to have the same arbitrary colour vision standard for seamen and cooks, and considered that for the non-seamen branches only total colour blindness and marked dichromatism should cause a handicap. They therefore recommended three grades for colour vision:

Grade 1 Highest standard

Signalmen and seamen must be able to recognise coloured lights at the greatest possible distance in every kind of weather. Colour vision requirement - ability to distinguish red, green and white navigation lights at a distance of 2-3 miles in clear weather without aids. Recruiting medical officers and ophthalmic specialists must also conform, to the standard.

Grade 2

To differentiate red, blue/green and white lights at short distances with aids. Shipwrights, artificers, blacksmiths, joiners, painters, plumbers, general medical personnel, Royal marines and bandsmen.

Grade 3

No colour vision requirement for cooks, valets, accountants, store-keepers etc.

They noted that some anomalous trichromats can be safely employed even in the seamen branch.

The authors recommended the use of the Ishihara test and a lantern test since they noted that no single test is infallible. They suggested a modified Board of Trade lantern for seamen and the Edridge-Green lantern as a subsidiary test.

Current Requirements

The colour vision requirements used today in the Royal Navy have changed little since that report. An additional grade has been added for trade situations.

Grade 1

To include pilots, helicopter pilots, navy airmen and seamen, air traffic control officers, air control officers and navigating officers.

Requirement: Correct recognition of coloured lights, shown through the small paired apertures on the Martin lantern at 6 metres.

Grade 2

Correct recognition of 13 out of 15 plates of the 24 page Ishihara test illuminated by artificial day light.

Grade 3

Correct recognition of coloured lights shown through the large paired apertures on the Martin lantern at 6 metres.

Grades 2 and 3 include W.R.N.S., Royal Marines, Officers, Clerks, Medical and dental officers, naval airmen employed as aircraft handlers, and engineers.

Grade 4

Correct recognition of colours used in relevant trades as assessed by simple tests e.g. coloured wires, resistors, filing tabs etc.

4. OTHER GROUPS

Army

Before the war colour deficiency was recorded but did not constitute a ground for rejection from services. Today the Army do not specify direct requirements except that "complete colour blindness may restrict choice of certain specialist Arms or corps, as an officer.

Officers must be red/green safe for commissions in Household Cavalry, Royal Engineers, Royal Signals, Special Air Services, Royal Corps of Transport, Ordnance Corps, R.E.M.E., Military Police, Intelligence Corps and flying duties.

'Complete colour blindness' restricts choice of employment in W.R.A.C. - but is acceptable for Queen Alexandra's Royal Army Nursing Corps.

The new Wright-Holmes Lantern has recently been adopted by the three Armed Services, Civil Aviation and the Merchant Navy to replace the lanterns used at present.

Police Force

The ability to distinguish the principal colours is all that is required.

Civil Service

For a number of grades within the Civil Service satisfactory colour vision is required, but the testing is left to the individual departments to use a method which is most suited to their requirements. This may involve the Ishihara test or may only require an answer to the question "Do you have difficulty in recognising colours".[1]

The grades for which a special slip "Colour Vision" should be attached to the health questionnaire:

All departments

Illustrator

Ministry of Agriculture, fisheries and food

Agriculture Development and Advisory Service (Science specialists)

Assistant Veterinary Investigation Officers (Grade B officers)

Science Group (all grades)

Veterinary research officers.

Ministry of Defence (Air Force Dept.)

Telecommunications Technical Officers

Telecommunications Technical Officers in the Meteorological Office

Professional and Technology of Officers Grade IV (Instruments and Electrical

1. Personal written communication from Dr. R Oliver, Senior Medical Officer, for the Civil Service 18th December 1973

Ministry of Defence (Air Force Dept. continued)

Radio Technicians

Examiners in the Quality Assurance Service (R.A.F.)

Ministry of Defence (Army Dept.)

Telecommunications Group BAOR

Ministry of Defence (Navy Dept.)

Professional and Technology Officers Grade IV (L)

" " " Grade III and IV

" " " Grade IV (Aircraft)

" " " (RNSS)

Cartographic Assistants

Cartographic Draughtsmen

Civil Hydrographic Officers

Chart Depot Assistants

Reproduction Grade A

Ministry of Defence (Procurement Executive)

Science Group (all grades)

Professional and Technology Officers and Engineering graduates.

Professional and Technology Officers

Government Communications Headquarters

Telecommunications Technical Officers

Home Office

Science Group (all grades) in the Forensic Science laboratories.

Ministry of Posts and Telecommunications

Telecommunications Technical Officers

National Coal Board

Surface and Underground Locomotive drivers and electricians are required to pass the Ishihara test.

Meteorological Office

Ishihara test is given to technical staff concerned with meteorological instrument development and maintenance and electricians.

B.B.C.

Engineering and Technical operators are given Ishihara test and F-M 100 Hue test in doubtful cases.

APPENDIX 3

LIST OF COMPANIES WHO COMPLETED AND RETURNED QUESTIONNAIRE

ELECTRICAL

Ashburton Resistance Company, London

R.S. Components, London E.C.1.

Erie Electronic Components, Great Yarmouth

Mullard, Blackburn

Electrosil, Sunderland

ITT. Standard Telephones and Cables London N.11

Sterling Cable Company, Reading

Telephone Cables Limited, Dagenham

A.E.I. Cables, Gravesend

B.I.C.C. Prescot

E.M.I., Hayes, Middlesex

Plessey Components, Swindon

Plessey Components, Romsey

Plessey Components, Liverpool

Zenith Electric Company, Milton Keynes

G.P.O.

Correspondance with:

Electric Cable Manufacturers Confederation, London W.1.

Electrical Research Association

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CARPETS

Brintons, Kidderminster
The Carpet Manufacturing Company, Kidderminster
Georgian Carpets, Kidderminster
Brockway Carpets, Kidderminster
Wilton Royal Carpet Company, Wilton
2 unidentified floor covering companies
Correspondence with:
"Carpet Review" - Journal

PHARMACEUTICAL/COSMETICS

Boots Company, Nottingham
Glaxo Laboratories
Parke Davis, Pontypool
Miles Laboratories, Glamorgan
Proctor & Gamble, Newcastle-on-Tyne
Smith & Nephew, Pharmaceuticals
Pharmax, Bexley
Ortho Pharmaceuticals, High Wycombe
The Wellcome Foundation, Dartford
Abbott Laboratories, Queenborough
I.C.I. Pharmaceuticals Division, Macclesfield
Avon Cosmetics, Northampton
Yardley Cosmetics, Basildon
Max Factor Cosmetics, Bournemouth
Rimmell Cosmetics, Ashford, Kent

Correspondence with:
The Association of the British Pharmaceutical Industry

GLASS
Pilkingtons Glass Limited, St. Helens
Redfearn National Glass Limited, York
Royal Brierley Glass, Brierley, Staffs.
Correspondence with:
British Glass Industry Research Association

/Continued....

PAINTS

R.J. Hamer & Sons, Mitcham

Associated Lead Manufacturers, London E.14

I.C.I. Paints, Slough

Thornley & Knight Limited, Birmingham

Paint Research Association, Teddington

Conway Dolman Products, London S.W.1

Carrs Paints, Birmingham

Industrial Colours Limited (Sericol Group) London S.W.6

Enfield Chemicals (Paints) Accrington

Dufay Paints, Shildon

Crown Paints, Darwen

Hunterseal, Tonbridge

CHEMICALS/PLASTICS

British Petroleum, Sunbury

Milk Marketing Board, Thames Ditton

Dunlop, Birmingham

British Oxygen Company, Wembley

Firestone Rubber Company, Brentford

Shell Limited, London S.E.1

I.C.I. (Plastics), Welwyn Garden

Yorkshire Chemicals, Leeds

Commercial Plastics, Cramlington

British Industrial Plastics (Chemicals Division) Warley

ESSO, London S.W.1.

ESSO Research Centre, Abingdon

Beechams Chemicals, Brentford

Correspondence with:

"Chemistry and Industry" - Journal of the Society of Chemical Industry

Chemical Industry Safety & Health Council of the Chemical Industries Association

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FOOD AND DRINK

Spillers, Cambridge
J. Lyons, London W.1.
Canada Dry, Crayford
Associated Biscuits, Reading
Associated Biscuits, Liverpool
Associated Biscuits, London S.E.16
Caxton Chocolate Company, London N.22
Walls Ice Cream, Gloucester
J. Sainsbury Limited, London S.E.19
Batchelors Foods, Ashford, Kent
Batchelors Foods, Worksop
Batchelors Foods, Sheffield
Coca-cola, Isleworth
Lea & Perrins, Worcester
Campbell's Soups, Kings Lynn
Smedley-HP Foods, Leamington Spa
Birds Eye, Walton-on-Thames
Pasta Foods, St. Albans
British Salt Limited, Middlewich
Viota Foods, Wirral
O.P. Chocolates Limited, Merthyr Tydfil
Walls Meat, London N.W.10
Brooke Bond-Oxo, Croydon
Quaker Oats, Southall
Carnation Foods, London N.2
Cadbury Schweppes, Birmingham
Cadbury Typhoo, Birmingham
Kellogg Company, Manchester
H.J. Heinz, London N.W. 10
Mars Limited, Slough
Nestle Company, Croydon
Findus Foods, Grimsby
Rowntree Mackintosh, York
British Sugar Corporation, Norwich
C. Shippam Meat Paste, Chichester

Food Colouring

Pointing Limited, Northumberland
Williams, Hounslow
Bush Boake Allen Limited

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CERAMICS/POTTERY

Twyfords, Stoke-on-Trent
H & R Johnson Tiles, Stoke-on-Trent
Doulton Sanitaryware, Stoke-on-Trent
Johnson Brothers, Stoke-on-Trent
Valson Enamelled Sanitary Fireclay Company, Stoke-On-Trent
Fireclay Tiles Limited, Stoke-on-Trent
Outran Ceramics, Burton-on-Trent
Spode Limited, Stoke-on-Trent
Royal Doulton Tableware Limited, Stoke-on-Trent
Worcester Royal Porcelain Company, Worcester
Wedgewood, Stoke-on-Trent
Royal Crown Derby Porcelain Company
Purbeck Pottery Limited, Bournemouth
Honiton Pottery, Honiton
Royal Vinton Works, Cheshire
English China Clays Limited St. Austell
Pilkingtons Tiles, Manchester

Correspondence with:

National Federation of Clay Industries
British Ceramic Research Association
British Ceramic Manufacturers Federation
British Ceramic Tile Council
Council of British Sanitaryware Manufacturers

METALS

International Nickel, Swansea
Metal Box Company, London N.W.10
Ductile Steels Limited, Willenhall
Balfour Darwins Limited Engineering Products, Sheffield
Dunford Hadfields Limited
Steel Castings Research & Trade Association
British Steel Corporation, Sheffield
Corporate Engineering Laboratory, British Steel Corp, London
2 unidentified Steel manufacturers
British Aluminium Company, London S.W.1

/Continued....

PAPER/PRINTING

G.F. Smith & Son, Coloured Paper, Hull

James Cropper, Kendal

Imperial Metal Industries (Printing Dept.), Birmingham

Wiggins Teape Research Centre, Beaconsfield

Wiggins Teape Mills, Dover

Horton Kirby Mills, Dartford

William Nash Mills, Orpington

Reed Engineering Services, Maidstone

I.P.C. (International Publishing Company), Hemel Hempstead

Odhams, Watford

John Dickinson Company

Inveresk Paper Company, Macclesfield

H.M.S.O., London W.C.2.

Harrison & Sons, High Wycombe

Reed Medway Sacks Limited, Maidstone

Thomas & Green Paper Mills, High Wycombe

Sommerville Papers, Scotland

Robert Stockwell Limited, London S.E.1.

Gee & Watson Engravers, London E.C.1.

Crown Wallcoverings Research Laboratory, Darwen

Sun Printers, Watford

Correspondence with:

Printing Packaging Industries Research Association

Ciba-Geigy Dyestuffs, Manchester (for a list of Paper Mills to whom they supply dyestuffs)

Wiggins Teape Research Laboratories, Beaconsfield

Associated Book Publishers Limited, London E.C.4.

London College of Printing, London S.E.1.

Printing & Publishing Industry Training Board

National Society of Operative Printers Graphical and Media Personnel (Natsopa)

National Graphical Association

/Continued.....

INKS

Coates Brothers, St. Mary Cray, Kent
Coates Brothers, London W.C.1.
Usher-Walker Limited, London W.C.2.
Wynne & Selby Limited, London W.C.2.
Society of British Ink Manufacturers, London W.C.2
Ault & Wiborg, Watford
Fishburn Inks, Watford
Lorilleux International, London N.17
Frank Horsell & Company, Leeds
Winstones Limited, Harefield, Middlesex
Colora Printing Inks, Harlow
Universal Printing Ink Company, Leeds
Reckitts Colours, Hull
Malcom Wade Company, London E.C.1
One unidentified Ink Manufacturer

BRICKS

Ibstock Bricks, Leicester
Nottingham Brick Company
London Brick Company
Correspondence with:
East Midland Brick Association

BREWING

Whitbread Brewery, London E.C.1

TOBACCO

British American Tobacco Company, London S.W.1
Gallaher Limited

RETAIL CLOTHES TRADE

Fenwick of Newcastle
The Burton Group, Leeds

LEATHER/CURRIERS

Richard Hodgson, Beverley, Yorkshire
British Leather Manufacturers Association

PENCILS

Keswick Pencil Company, Keswick

/Continued.....

TIMBER/FURNITURE

Timber Research Association
Clover Mill (Furniture), Nelson
Walker & Homer Group, Warley
Revelesse Limited, Brinkway, Cheshire
Ercol Furniture, High Wycombe
Furniture Industry Research Association (correspondence as well)

AUTOMOBILE INDUSTRY

Austin Morris Division, British Leyland, Oxford
Vauxhall Motors, Luton
Correspondence with:
Motor Industry Research Association

NATIONAL GAS BOARDS

North Thames Gas
North East Gas
East Midland Gas
Wales Gas
Scottish Gas
North West Gas

NATIONAL ELECTRICITY BOARDS

North West Electricity
London Electricity
South Eastern Electricity

MISCELLANEOUS ORGANISATIONS

British Railways
London Transport
Meteorological Office
British Broadcasting Company B.B.C.
National Coal Board
Metropolitan Police Office
Department of Employment, Medical Advisory Service
Royal National Life-Boat Institution

TEXILES/DYERS

Ciba-Geigy, Pigments, Paisley
Ciba-Geigy, Pigments, Manchester
George Lee & Sons, Wakefield
Tootal Fabric Division Research, Hyde
Stevensons Dyers Limited, Ambergate
Brocades, Great Britain Limited, Weybridge
Pretty Polly Ladies Hosiery, Sutton-in-Ashfield
Pasolds, Slough
E. Fogarty & Company, Boston
Bunnel & Company, London E.14
Bembrose Limited, Spondon
Hoechst (UK) Limited, Manchester
Courtaulds Limited, Manchester
Saxby Dyes, Nottingham
Abbey Meadow Mills, Leicester
International Wool Secretariat, Ilkley
Patons, Darlington
Furzebrook Knitting Company, Spondon
Hosiery & Allied Trades Research Association, Nottingham
Meridian Dyes, Nottingham
Corah, Leicester
Shirley Institute, Manchester (Cotton & Man-made Fibres Research Association)
Sandoz Products, Leeds
Henry Ashwell, Nottingham
Olympia Corduroy, Rochdale
The Standish Company, Wigan
Kimberley-Clark, Maidstone
Coates Brothers, Sidcup
Argyll Wools, Pudsey
I.C.I. Organics Division, Manchester
English Sewing Limited, Manchester
Sericol Group, London S.W.6.

Correspondence with:

Lambeg Industrial Research Association, Northern Ireland (formerly Linen Industry Research Association)

Society of Dyers and Colourists, Bradford.

/Continued....

APPENDIX 4
INDUSTRIAL VISITS MADE BY THE AUTHOR

TEXTILES/DYES/CARPETS

Hoisery & Allied Trade Research Association (HATRA)
Nottingham

Meridian Dyehouse, Nottingham

Shirley Institute (Cotton & Silk & Man-made Fibres Research Association), Manchester

Courtaulds Limited, Research Division, Manchester

I.C.I., Organics Division, Manchester

Wool Industries Research Association, Leeds

Brookfoot Dye Company, Brighouse, Leeds

Birstall Carpet Company, Birstall, Leeds

Bulmer & Lumb Fabrics, Leeds

Wood Bastow, Nottingham (Suppliers to Marks & Spencer)

Wilton Royal Carpet Company, Wilton

FOOD INDUSTRIES

Kellogg's, Manchester

H.J. Heinz, London N.W.10

Mars, Slough

Cadbury Schweppes, Birmingham

Food Industries Research Association, Leatherhead, Surrey

Batchelors Foods, Ashford, Kent

Meat Research Institute, near Bristol

/Continued.....

CERAMICS/POTTERY INDUSTRIES

British Ceramics Research Association, Stoke-on-Trent

Twyfords Sanitary Ware, Stoke-on-Trent

H.&R. Johnson Tiles, Stoke-on-Trent

Worcester Royal Porcelain Company, Worcester

Wedgewood, Stoke-on-Trent

PAPER MILLS

Wiggins Teape Mills, Dover

William Nash Mills, Orpington, Kent

COLOUR PRINTING

Odhams Limited, Watford

Sun Printers, Watford

Harrison & Sons, High Wycombe (Postage Stamps)

Gee & Watson Engravers, London E.C.1

I.P.C. International Publishing Company, Hemel Hempstead

London College of Printing, London S.E.1

PRINTING INKS

Coates Brothers, St. Mary Cray, Kent

Ault & Wiborg, Watford

Fishburn Inks, Watford

ELECTRICAL

E,M.I. Hayes, Middlesex

Mullard Blackburn

Erie Resistor Company, Great Yarmouth

I.T.T. Standard Telephones & Cables, London N.11

Electricity Council London S.E.1

G.P.O. Training School, London E.C.1.

PHARMACEUTICAL/COSMETICS

Abbott Laboratories, Queenborough, Kent

Max Factor, Bournemouth

/Continued...

MISCELLANEOUS INDUSTRIES

TOBACCO

British American Tobacco Company

AUTOMOBILE

Vauxhall Motors, Luton

TRANSPORT

London Transport - Chief Medical Officer

MINERALS

British Steel Corporation, Research Laboratory, London S.E.19

Diamond Grading

APPENDIX 5
LIST OF MISCELLANEOUS CORRESPONDENCE

MEDICAL

Association of Anaesthetists of Great Britain and Ireland

Association of Medical Officers of Health

Society of Occupational Medicine

Royal Society of Health

Association of Optical Practitioners (Occupational Visual Welfare Committee)

Civil Service Medical Adviser

Trade Union Council Medical Adviser

London Transport Medical Adviser

British Railways Board Medical Adviser

Royal National Life-Boat Institution Medical Adviser

West Midlands Industrial Health Service

Health and Safety Executive (Employment Medical Advisory Service)

West Midlands Region:	Dr. M.D. Kipling
	Dr. D. Smith
South Western Region:	Dr. G. Ritchie
Northern Region:	Dr. J. Bell
North Western Region:	Dr. G. Fletcher
Scotland:	Dr. E. Blackadder
Wales:	Dr. A. Jones
London & South East Region:	Dr. K. Duncan
	Dr. F. Neild
Eastern and South East Midlands Region:	Dr. D. Trott

INDIVIDUALS

Dr. W.O.G. Taylor, Consultant Ophthalmologist, Ayr Hospital

Dr. M. Pleydell, Oxfordshire Area Health Authority

Dr. P. Aspinall, University of Edinburgh, Ophthalmology Dept.

Dr. G. Verriest, University of Ghent, Belgium, Ophthalmology Dept.

Dr. R. Sproull, U.S.A.

Mr. R.S. Adlington, Safety Officer, Brunel University

Dr. D. Miller, Medical Adviser, Marks & Spencer Limited

/Continued.....

INDUSTRIAL AND OTHERS

Royal Society for the Prevention of Accidents (ROSPA)
(Senior Technical Officer, Industrial Safety Division, also Road Safety Division)

British Safety Council

Associated Society of Locomotive Engineers & Fireman (ASLEF)

Wool Industries Research Association

Shoe and Allied Trade Research Association

Printing & Packaging Research Association

H.M.S.O. Group Training Officer

British Standards Institution (Technical Officers)

Moore & Son Limited, Market Gardeners, Wimbourne, Dorset

INDIVIDUALS

Dr. R. Lakowski, Univ ersity of British Columbia, Canada

Professor G. Ball, Ophthalmic Optics Dept., Aston University

Professor Atherly, Occupational Health Dept., Aston University

Miss J. Grant, Food Industries Research Association

Mrs J. Poplett - who wrote a minor thesis on career guidance and colour vision

Mr. H. Darrell, Senior Lecturer, Cambridge College of Art and Technology

Mr. R. Gulliford, Senior Lecturer, University of Birmingham School of Education

Dr. J. Alexander, School of Optometry, University of New South Wales, Australia

Mr. D. Irving, Leyland Paint & Wallpaper Limited

Mr. R. Goacher, Ophthalmic Optician, Leeds (interested in industrial vision)

/Continued....

APPENDIX 6
LIST OF MISCELLANEOUS TELEPHONE CALLS

Knitting, Lace & Net Industry Training Board
Mr. A. Woolrich, Manager Development Services

Dr. A. MacDougal, Meat Research Institute, near Bristol

British Federation of Master Printers, London

British Master Printers Association - Mr. Nightingale
London Master Printers Association Mr. Putman

Bowater Paper Mills - Mr. D. McConnel

Wiggins Teape Paper Mills - Mr. Goldsmith

Reed Paper Mills, Maidstone - Mr. Wilson

Industrial Printers, London S.E.10 - Mr. Spanner

I.C.I., Manchester - Mr. Harvey

G.P.O. Psychological Services Board - Mr. Ferness
Mrs. Dufort

Henry Richard Printers, London S.E.11

British Electrical & Allied Manufacturers Association
- Mr Reed

Electrical Cable Manufacturers Confederation, London

Printing Industry Training Board - Mr. Dixon

Dr. Slatter, Medical Adviser, Tintometer Limited, Salisbury

Instrumental Colour Systems - Mr. Perry

Department Health & Social Security - Dr. Jones

APPENDIX 7
COLOUR VALUES OF RESISTORS AND CAPACITORS.

(taken from B.S. 1852 (1967) as amended May 1972)

Colour	B.S.381C colour no.	1st figure	2nd figure	Multiplying Value	Tolerance percent
Silver	-	-	-	10^{-2}	±10
Gold	-	-	-	10^{-1}	± 5
Black	-	-	0	1	-
Brown	412	1	1	10	± 1
Red	538	2	2	10^2	± 2
Orange	557	3	3	10^3	-
Yellow	355	4	4	10^4	-
Green	221	5	5	10^5	-
Blue	166	6	6	10^6	-
Violet	796	7	7	10^7	-
Grey	632	8	8	10^8	-
White	-	9	9	10^9	-
None/ Pink	-	-	-	-	±20

DETAILS OF RESISTORS USED IN TRIAL

Resistors were numbered 1,2,3,4,5,7,8 and in alphabetical order A - T. They were chosen from several different manufacturers.

Resistors 1 - 8

These were the larger set of resistors and all had a dark brown background.

Coloured Bands

No.1 Blue, Red, Orange, Gold
No.2 Brown, Blue, Orange, Gold
No.3 Brown, Green, Orange, Gold
No.4 Red, Black, Orange, Gold
No.5 Red, Red, Orange, Silver
No.7 Orange, White, Black, Silver
No.8 Yellow, Violet, Orange, Silver

Size of Resistors 1 - 8

No.1 - No.3

Overall length 18mm.
Overall length occupied by bands 12mm.
Overall width 8mm.

(Although observers were free to rotate resistors, the overall length of band exposed = overall width of resistor 8mm.)

Bands 2mm wide
Separated by 1mm gap
Length of band 8mm.

No.4

Overall length 18.5mm.
Overall width 6mm.
Band width 2mm.
Band length 6mm.

No.5

Overall length 15mm.
Overall width 6mm.
Band width 1mm.
Band length 6mm.

No.7 & No.8

Overall length 14mm.
Overall width 5mm.
Band width 1mm.
Band length 5mm.

/Continued.....

Resistors A - T

Coloured Bands

A. Blue, Grey, Black, Silver (Light Green background)
B. Yellow, Mauve, Black, Silver (Brown background)
C. Red, Black, Brown, Gold (Brown background)
D. Green, Blue, Black, Silver (Brown background)
E. Yellow, Mauve, Brown, Silver (Brown background)
F. Green, Blue, Brown, Silver (Brown background)
G. Brown, Black, Black, Gold (Light Brown background)
H. Brown, Red, Orange, Gold (Light Brown background)
I. Red, Mauve, Orange, Gold (Light Brown background)
J. Brown, Green, Orange, Gold (Light Brown background)
K. Blue, Grey, Yellow, Gold (Yellow background)
L. Green, Blue, Brown, Gold (Yellow background)
M. Yellow, Mauve, Yellow, Gold (Yellow background)
N. Blue, Grey, Green, Gold (Dark Red background)
O. Red, Yellow, Yellow, Red (Dark Red background)
P. Brown, Brown, Red, Gold (Dark Red background)
Q. Yellow, Mauve, Orange, Gold (Beige background)
R. Brown, Red, Brown, Gold (Beige background)
S. Blue, Grey, Orange, Gold (Beige background)
T. Brown, Black, Brown, Gold (Brown background)

Size of Resistors A - T

No. A,K,L,M

Overall length 10mm.
Overall width 4mm.
Band width 0.5 - 1.0 mm. (variable)
Band length 4mm.

No. B,C,D

Overall length 9mm.
Overall width 3.5mm.
Band width 0.75 - 1.0 mm. (variable)
Band length 3.5 mm.

No. E & F

Overall length 10mm.
Overall width 3mm.
Band width 0.75 - 1.0 mm.
Band length 3mm.

No. G,H,I,J

Overall length 8mm.
Overall width 2.5mm.
Band width 1mm.
Band length 2.6mm.

/Continued.....

Size of Resistors A - T (cont.)

No. O,P,N,O,R,S

Overall length 10mm.
Overall width 3mm.
Band width 0.5 - 1.0mm.
Band length 3mm.

No.T

Overall length 6mm.
Overall width 2mm.
Band width 0.5mm.
Band length 2mm.

APPENDIX 8
DETAILS OF CAPACITORS USED IN TRIAL

Capacitors were numbered 1,2,3,6,7,8,10,11,12,16,17,18,19, 22,23,25,26,28. They were all from one manufacturer.

Coloured Bands

No.1 Brown, Black, Green, White, Red
No.2 Brown, Green, White, Red
No.3 Brown, Green, Black, Red
No.6 Red, Yellow, Black, Yellow
No.7 Brown, Green, Yellow, Black, Yellow
No.8 Yellow, Violet, Yellow, White, Red
No.10 Yellow, Violet, Yellow, Black, Red
No.11 Orange, Yellow, White, Red
No.12 Blue, Grey, Orange, Black, Yellow
No.16 Brown, Red, Orange, Yellow, Red
No.17 Red, Yellow, White, Red
No.18 Brown, Green, Orange, White, Red
No.19 Brown, Black, Orange, Black, Red
No.22 Brown, Black, Yellow, Black, Red
No.23 Brown, Black, Orange, Black, Yellow
No.25 Brown, Green, Yellow, Black, Red
No.26 Brown, Black, Orange, Black, Yellow
No.28 Brown, Green, Orange, White, Yellow

Size of Capacitors

Dimensions indicate size of bands since no background colour is present.

1.	27mm. long	1-2mm. wide	(variable)
2.	26mm. long	2-5mm. wide	(variable)
3.	26mm. long	2-5mm. wide	(variable)
6.	20mm. long	1-4mm. wide	(variable)
7.	20mm. long	1-2mm. wide	(variable)
8.	19mm. long	1-2mm. wide	(variable)
10.	20mm. long	1-2mm. wide	(variable)
11.	19mm. long	1-3mm. wide	(variable)
12.	14mm. long	1-2mm. wide	
16.	10mm. long	1-2mm. wide	
17.	15mm. long	1-5mm. wide	
18.	12mm. long	1-3mm. wide	
19.	11mm. long	1-2mm. wide	
22.	11mm. long	1-3mm. wide	
23.	10mm. long	1-2mm. wide	
25.	13mm. long	1-2mm. wide	
26.	10mm. long	1-2mm. wide	
28.	10mm. long	1-1.5mm. wide	

Observations The top (first) band was often the widest. The last two (bottom two) were usually the narrowest.

APPENDIX 9

COLOUR VISION TEST PERFORMANCE

Deuteranopic Observers

Number	Age	100 Hue Score	100 Hue Axis	HRR Errors	Ishihara Errors	Ishih Diag.	D15 Cross	D15 Diag.	10/19 Errors	CVA Range	Nagel Range
D 1	20			14	20	None	10	D		140	Full 75
D 2	28	202	D	13	20	D	10	D	8	140	Full 75
D 3	25	145	D	8	20	D	12	D			Full 75
D 4	68	384	D	15	20	D	13	D	7	140	Full 75
D 5	19	213	D	9	20	D	12	D	7	140	Full 75
D 6	25	182	D	12	20	D	14	D	8	140	Full 75
D 7	26	170	D	12	20	D	12	D	10		Full 75
D 8	19	207	D	11	20	D	10	D	8	140	Full 75
D 9	25			9	20	D	11	D	10		Full 75
D10	40	260	D	14	20	D	10	D	10	140	Full 75
D11	68	226	D	13	20	None	12	D		140	Full 75
D12	22	199	D	13	20	D	7	D	9	130	Full 75
D13	20	161	D		20	D	10	D	8	70	Full 75
D14	55	297	D	14	20	D	10	D	9	140	Full 75
D15	21			8	20	D	10	D	9	140	Full 75
D16	25	219	D	12	20	D	12	D	10	140	Full 75
D17	15	343	D	11	20	None	11	D	8		Full 75
D18	52	265	D	13	20	D	7	D	9	140	Full 75
D19	57	278	D	14	20	D	5	D	6	140	Full 75
D20	57	290	D	9	20	D	12	D	8	140	Full 75
D21	60	249	D	12	20	D	9	D	9	105	Full 75
D22	24	147	D	6	20	D	11	D	10	140	Full 75
D23	28			14	19	D	12	D	10		Full 75
D24	62	235	D	12	20	D	10	D	7	140	Full 75
D25	12			9	20	D	12	D	9	95	Full 75
D26	20	76	D	10	20	D	8	D	4	115	Full 75
D27	28	416	D	14	17	D	12	D	8	140	Full 75
D28	18	206	D	10	20	D	12	D	8	140	Full 75
D29	38				20	D	8	D	5	140	Full 75
D30	22	212	D	13	20	D	12	D	9		Full 75

COLOUR VISION TEST PERFORMANCE

Protanopic Observers

Number	Age	100 Hue Score	100 Hue Axis	HRR Errors	Ishihara Errors	Ishih Diag.	D15 Cross	D15 Diag.	10/19 Errors	CVA Range	Nagel Range	Nagel Midpoint
P 1	20	163	P	11	20	P	13	P	10	135	Full 75	
P 2	60	189	P	12	20	P	12	P	10	140	Full 75	
P 3	25	149	P	8	20	P	11	P	10	140	Full 75	
P 4	20	186	P	12	20	P	11	P	10	140	Full 75	
P 5	20	109	P	11	19	P	7	P	10	130	Full 75	
P 6	24	128	P	11	20	P	13	P	10	140	Full 75	
P 7	35			11	20	None	11	P	10	140	Full 75	
P 8	63	259	P	13	20	None	11	P	9	140	Full 75	
P 9	35	332	P	8	20	P	13	P	10	140	Full 75	
P10	32	164	P	12	20	P	10	P	9	140	Full 75	
P11	21	70	P	6	20	P	10	P	9	140	Full 75	
P12	56	102	P	11	20	P	8	P	10	140	Full 75	
P13	20	187	P		20	P	11	P	9	140	Full 75	
P14		120					11	P	9	140	Full 75	
P15		214	P	10	20	P	11	P	10	140	Full 75	

Protanomalous Observers

P16	17	97	P	7	18	None	None	None	2	140	68	36
P17	18	32	None	12	20	None	2	None	None	45	65	32
P18	19	46	None	3	7	None	1	None	None	30	28	54
P19	48	149	None	14	20	P	None	None	2	135	20	50
P20	34	121	P	11	20	P	2	None	5	50	18	53
P21	20	107	P	11	9	None	2	P	1	40	16	54
P22	68	56	None	14	19	None	None	None	1	25	15	57
P23	51	142	None	11	16	None	7	None	4	130	15	57
P24	17	52	None	14	19	None	None	None	1	25	7	63
P25	25	66	P	4	16	None	1	None	None		3	62

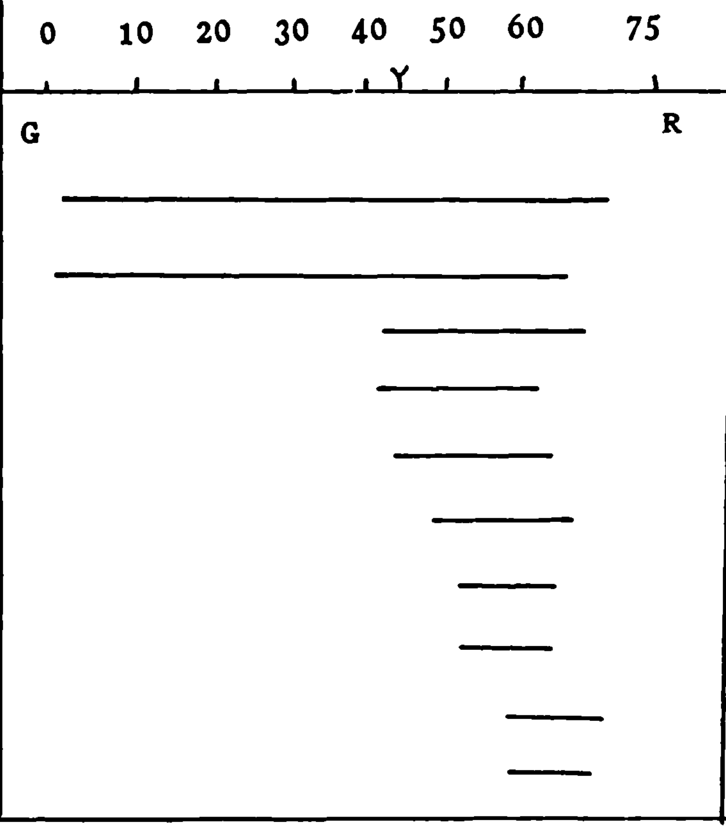
COLOUR VISION TEST PERFORMANCE

Deuteranomalous Observers

Number	Age	100 Hue Score	100 Hue Axis	HRR Errors	Ishihara Errors	Ishih Diag.	D15 Cross	D15 Diag.	10/19 Errors	CVA Range	Nagel Range	Nagel Midpoint
D31	31	142	D	10	20	D	10	D	10		55	27
D32	68	273	D	9	16	D	8	D	8	140	47	24
D33	47	138	D	12	20	D	5	D	1	55	45	23
D34	52			11	20	D	12	D	9	140	45	23
D35	45				20	D	10	D	5		44	22
D36	32	206	D	8	20	D	10	D	9	110	43	21
D37	40			12	20	D	8	D	4		42	21
D38	20	95	None	4	20	D	None	None	None	35	42	28
D39	50	170	None	11	20	D	3	D	2	40	41	20
D40	45	192	D	12	20	D	6	D			41	21
D41	50	173	D	8	20	D	7	D	5	25	40	20
D42	25	204	D	6	20	D	2	D	2	140	38	19
D43	17	272	D	6	20	D	4	None	None	50	36	18
D44	19	93	None	11	20	D	1	None	1	55	35	17
D45	58			10	20	D	7	D	3		35	29
D46	43	191	D	12	20	D	9	D	9	90	35	17
D47	28	134	D	14	20	D	6	D	9	140	34	40
D48	22	104	None	8	18	D	None	None	None	70	30	15
D49	20	103	None	2	8	None	None	None	None	60	20	17
D50	21	100	D	8	20	D	None	None		55	20	22
D51	28	25	None	2		7	None	None	None	135	19	15
D52	25	174	D	2	15	D	None	None	1	50	19	20
D53	15	46	None	6	20	D	None	None	None		19	23
D54	17	108	D	8	20	D	None	None	5	65	18	16
D55·	45	84	None	3	11	D	None	None	1	20	18	14
D56	50			6	20	D	6	D	9	140	18	20
D57		83	D	11	20	D	None	None	None	70	15	17
D58	30	83	None	6	20	D	2	None	2	60	15	17
D59	23	54	D	9	20	D	None	None	1	77	14	17
D60	17	209	None	9	18	D	1	None	1		12	19
D61	37	179	D	5	20	D	9	D	3	35	12	11
D62	19			2	5	None	None	None	None		12	14
D63	45	70	None	6	20	D	None	None		50	11	19
D64	28	51	None	1	7	None	None	None	None	30	7	21
D65	20	121	D	9	15	D	2	None	None	70	6	23
D66	24	95	D	4	13	D	None	None	None	30	6	28
D67	19	28	None	None	5	None	None	None	None	50	5	17
D68	47	86	None	6	16	D	None	None	None	20	5	24
D69	55	68	None	1	4	None	None	None	None	80	4	22
D70	22	83	D	4	20	None	12	None	None		4	22
D71	24	38	None	1	10	None	None	None	None	25	3	21

ANOMALOSCOPE DATA

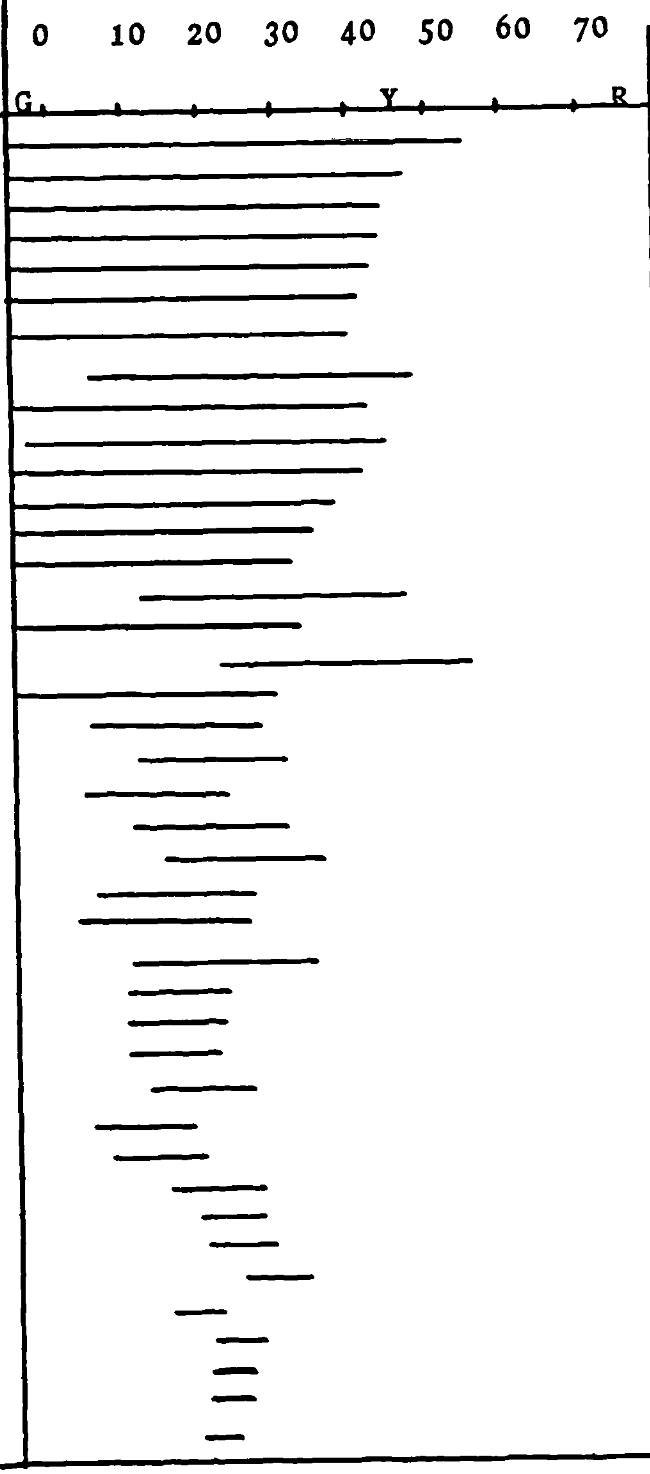
Protanomalous Observers



No.	Nagel Range Best Eye		Midpoint Best Eye
P16	2 - 70	68	36
P17	1 - 65	65	32
P18	40 - 68	28	54
P19	40 - 60	20	50
P20	44 - 62	18	53
P21	48 - 64	16	54
P22	50 - 65	15	57
P23	50 - 65	15	57
P24	60 - 67	7	63
P25	61 - 64	3	62

ANOMALOSCOPE DATA

Deuteranomalous Observers



No.	Nagel Range	Best Eye	Midpoint Best Eye
D31	0 - 55	55	27
D32	0 - 47	47	24
D33	0 - 45	45	23
D34	0 - 45	45	23
D35	0 - 44	44	22
D36	0 - 43	43	21
D37	0 - 42	42	21
D38	7 - 49	42	28
D39	0 - 41	41	20
D40	1 - 42	41	21
D41	0 - 40	40	20
D42	0 - 38	38	19
D43	0 - 36	36	18
D44	0 - 35	35	17
D45	12 - 47	35	29
D46	0 - 35	35	17
D47	23 - 57	34	40
D48	0 - 30	30	15
D49	7 - 27	20	17
D50	12 - 32	20	22
D51	6 - 25	19	15
D52	11 - 30	19	20
D53	14 - 33	19	23
D54	7 - 25	18	16
D55	5 - 23	18	14
D56	13 - 31	18	20
D57	10 - 25	15	17
D58	10 - 25	15	17
D59	10 - 24	14	17
D60	13 - 25	12	19
D61	5 - 18	12	11
D62	8 - 20	12	14
D63	14 - 25	11	19
D64	18 - 25	7	21
D65	20 - 26	6	23
D66	25 - 31	6	28
D67	15 - 20	5	17
D68	22 - 27	5	24
D69	20 - 24	4	22
D70	20 - 24	4	22
D71	19 - 22	3	21

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THE CITY UNIVERSITY

Department of Ophthalmic Optics and Visual Science

Cranwood Street, London E.C.1

BRIEF QUESTIONS ON ENDOSCOPIC COLOUR VISION

Thank you for helping with this short survey - please hand it in before you go. Delete incorrect answers.

1. Have you ever had a colour vision test? YES/NO

2. If "YES", was it to see if you had defective colour vision BEFORE you started medicine or DURING your training? BEFORE/DURING

   (Add brief details here ....
   ....)

3. Do you have any difficulty identifying colours? YES/NO

4. If "YES", is it a handicap for endoscopy? YES/NO

   (Add elaboration here or p.t.o. ....
   ....)

5. If you have a colour vision difficulty does this extend to other medical tasks? YES/NO

   (Add elaboration here or p.t.o. ....
   ....)

6. How does colour play a role in endoscopy?

   ....
   ....
   ....

7. Do different instruments give apparent colour differences (e.g. with a given lesion)? YES/NO

8. Can you name any endoscope/s which give you good (or bad) colour appearances?

   Details ....

9. Can we help by suggesting contrast filters? YES/NO

   (Please write address, etc. on reverse side)

Please contact us if we can help with further examination of your colour vision.

Mrs. Janet Yoke (Research Assistant)
Prof. Robert Fletcher (Head of Dept.)

March 1976

THE CITY UNIVERSITY LONDON

DEPARTMENT OF OPHTHALMIC OPTICS & VISUAL SCIENCE

MINATURE & ENDOSCOPIC SPOT TESTS. SUBJECT..............................

Date ..../76 Illumn............

Insteuctions: " Please tell me the number of coloured spots on each square. Coloured spots have been cut out and then put back. Some are still the original colour & you can see the round cut. Do not count these. Some have been replaced with different colours from the square...please count the different ones."

MINAIURE.

SQUARE	SUBJECT SAYS	NORMAL	PROT	DEUT	TRIT	DIAGNOSIS
X		2	-	-	-	
Y		3	-	-	-	
a		3	1	2	(3)	
b		4	1	3	(4)	
c		5	2	3	(5)	
d		4	3	1	(4)	
e		4	4	2	(3)	
f		3	1	3	(2)	
g		5	3	(5)	4	
h		4	(4)	3	1	
i		7	5	4	6	
j		7	4	6	5	

ENDOSCOPIC.

SQUARE	SUBJECT SAYS	NORMAL	PROT	DEUT	TRIT	DAIGNOSIS
X		2	-	-	-	
Y		3	-	-	-	
A'		3	1	2	(3)	
B'		4	1	3	(4)	
C'		5	2	3	(5)	
F'		3	1	2	(3)	
G'		4	(4)	3	1	
H'		3	(3)	2	1	
M'		6	3	4	(6)	

NUMBERS IN BRACKETS — IGNORE FOR DIAGNOSIS.

RF March 76.

THE CITY UNIVERSITY

DEPARTMENT OF OPHTHALMIC OPTICS AND VISUAL SCIENCE

COLOUR VISION TESTING IN SCHOOLS

Name of Region/Area:

Name of Principal School Medical Officer:

1. Is a colour vision test given to children in your region/area as part of the routine school medical examination?

   YES / NO (Delete one)

   If yes, please state:

   (a) What test is used?

   (b) At what age/s it is given?

   (c) By whom it is administered:

   (d) Whether it is given to girls as well as boys?

   (e) What action is taken if a colour defective child is diagnosed?

2. Are facilities for career guidance available for colour defective children?

3. Are teachers in the school informed of the difficulties colour defective children may experience?

4. Please give brief details of how the choice of test/s used was made.

5. You are invited to add any other comments relevant to this study.

Please return to: Ms. J. Voke, B.Sc.(Hons.), Research Assistant,
Department of Ophthalmic Optics and Visual Science,
The City University, Cranwood Street, London E.C.1

THE CITY UNIVERSITY

CRANWOOD ANNEXE · CRANWOOD STREET · LONDON EC1V 9HH

DEPARTMENT OF OPHTHALMIC OPTICS AND VISUAL SCIENCE

Telephone: 01-253 4399

JV/MMcK

Principal School Medical Officer

Dear Sir/Madam,

I am conducting a research investigation, sponsored by the Medical Research Council, into the occupational and industrial consequences of colour vision defects, in this Department. I am anxious to know to what extent colour vision testing is carried out as part of the school medical examination in the U.K., at what age this is done, and what test is used. It would greatly assist my work if you would kindly return the enclosed questionnaire on this subject to me at your earliest convenience.

Thank you for your help.

Yours sincerely,

Janet Voke

Janet Voke, B.Sc.(Hons.)
Research Assistant.

CROYDON AREA HEALTH AUTHORITY

J. Stuart Horner, O.St.J., M.B., Ch.B., M.F.C.M., D.P.H., D.I.H.

Telephone 01-686 4433
Ext: 2145
Your ref:
My ref: SHS/B4/SAH
Date

Area Medical Officer,
Room 3-01,
Taberner House,
Park Lane,
Croydon. CR9 3BT

Dear Madam,

Colour Vision.

At a recent school medical inspection it was found that your child has defective colour vision. The defect is a permanent one and no treatment is either necessary or possible. It is likely that your child has learned to associate colours fairly well so that the defect may not be apparent to you. Defective colour vision is often present in several members of the same family and an uncle or brother may also be affected.

Colour vision is quite different from the general sight in the eye and it is NOT necessary to visit an optician. The defect is unlikely to affect your child although some occupations will not accept employees with defective colour vision. On grounds of colour vision young people have been known to be excluded from certain branches of all the defence services, the Police Force, Public Transport, the Merchant Navy, Civil Aviation and some types of electrical and tele-communication work where multi-coloured wiring or signal systems are involved. In order to avoid later disappointment steps should be taken at an early stage to discover if defective colour vision is a bar to any particular occupation.

If you are still worried about this defect, you should telephone the School Health Service, at the extension shown above, when an appointment will be made for you to discuss the matter with a School Medical Officer.

Yours faithfully,

J. Stuart Horner.

Area Medical Officer.

SEFTON AREA HEALTH AUTHORITY

SCHOOL HEALTH SERVICE

CLINIC:

Date:

Dear Parent or Guardian,

It has been brought to my notice that ....
has some difficulty with colour vision. This condition does not require treatment, and in other respects the eyesight is normal.

Usually this does not affect future employment in any way unless the child wishes to take up a position where it is essential to have normal colour vision, e.g. a guard on a train, a navigator or pilot, a textile designer and some electrical work where colour coding is used.

I am therefore giving you this information so that when your son/daughter is thinking about his/her future career, this condition can be borne in mind.

Yours faithfully,

Clinical Medical Officer

With the Compliments of
Mr. T.J. SALMON, Production Director,
Horton Kirby Paper Mills Ltd.

:SITY

LONDON ECIV 9HH

VISUAL SCIENCE

SOUTH DARENTH
Nr. DARTFORD
KENT

Questionnaire

Please return to Mrs. J. Voke
Department of Ophthalmic Optics and Visual Science
The City University, Cranwood Street, London, E.C.1.

1. Do any tasks in your organisation demand colour judgement and hence good colour vision? If so, what areas and how many people does this affect?

Yes - Colour matching grades of paper continuously.

This affects the main production areas and involves 6 men out of a total of 36.

2. Are any of your employees given a colour vision test.

✓ YES/NO (Delete one)

If yes, please state:

a) what test is used? ISHIHARA

b) To whom it is given? FOREMEN & BEATERMEN

c) By whom it is administered? LABORATORY & STAFF

RP$

T.C.U. MAXIMOR SYSTEM (MAPK 3A)

TYPE JOB NUMBER- DPO-A024
DATE: 23/06/76 CHANNEL: 2
13-33-40- DPFN DPA024-1674
13-34-05- LOAD CR06
LOADED
13-35-42- CRUN
-08
-01 3B
-02 3A
-03 3C
-04 5B
-05 6F
-06 4C
-07 7E
-08 5A

CIE 2 DEGPEE CHROMATICITY COORDINATES

	CXA	CYA	CZA	CLA	CXB	CYB	CZB	CLB
1 3B	0.4987	0.3935	0.1078	0.4305	0.4566	0.4025	0.1408	8.1615
2 3A	0.5008	0.3939	0.1053	0.4098	0.4587	0.4034	0.1379	7.7604
3 3C	0.5033	0.3857	0.1110	0.4542	0.4611	0.3933	0.1456	8.5552
4 5B	0.5011	0.3917	0.1072	0.4244	0.4548	0.4034	0.1418	7.9956
5 6F	0.4985	0.3897	0.1119	0.4511	0.4532	0.3996	0.1471	8.5151
6 4C	0.4945	0.3957	0.1099	0.4589	0.4486	0.4071	0.1443	8.7027
7 7E	0.4944	0.3957	0.1099	0.4597	0.4486	0.4072	0.1443	8.7186
8 5A	0.5060	0.3859	0.1082	0.4116	0.4599	0.3965	0.1436	7.7108

	CXC	CYC	CZC	CLC	CXD	CYD	CZD	CLD
1 3B	0.3617	0.3292	0.3091	0.4012	0.3644	0.3389	0.2967	0.3937
2 3A	0.3646	0.3326	0.3027	0.3814	0.3672	0.3421	0.2907	0.3791
3 3C	0.3629	0.3176	0.3195	0.4184	0.3660	0.3269	0.3071	0.4151
4 5B	0.3591	0.3307	0.3102	0.3975	0.3614	0.3417	0.2970	0.3968
5 6F	0.3560	0.3245	0.3195	0.4223	0.3586	0.3350	0.3064	0.4209
6 4C	0.3535	0.3329	0.3136	0.4341	0.3557	0.3441	0.3001	0.4337
7 7E	0.3534	0.3329	0.3136	0.4349	0.3557	0.3442	0.3001	0.4345
8 5A	0.3621	0.3230	0.3149	0.3814	0.3647	0.3335	0.3018	0.3801

	CUA	CVA	CWA	CUB	CVB	CWB
1 3B	0.2966	0.3511	0.3523	0.2641	0.3492	0.3789
2 3A	0.2979	0.3514	0.3507	0.2650	0.3496	0.3771
3 3C	0.3040	0.3495	0.3465	0.2713	0.3472	0.3748
4 5B	0.2992	0.3509	0.3499	0.2625	0.3492	0.3782
5 6F	0.2985	0.3501	0.3514	0.2632	0.3481	0.3801
6 4C	0.2926	0.3512	0.3561	0.2568	0.3495	0.3838
7 7E	0.2925	0.3512	0.3562	0.2567	0.3496	0.3839
8 5A	0.3058	0.3498	0.3444	0.2690	0.3479	0.3738

	CUC	CVC	CWC	CUD	CVD	CWD
1 3B	0.2323	0.3172	0.4505	0.2300	0.3208	0.4492
2 3A	0.2329	0.3187	0.4484	0.2305	0.3222	0.4473
3 3C	0.2386	0.3131	0.4483	0.2365	0.3168	0.4467
4 5B	0.2298	0.3175	0.4527	0.2267	0.3215	0.4519
5 6F	0.2304	0.3149	0.4547	0.2276	0.3189	0.4535
6 4C	0.2249	0.3177	0.4574	0.2217	0.3217	0.4566
7 7E	0.2248	0.3177	0.4575	0.2216	0.3217	0.4566
8 5A	0.2354	0.3150	0.4495	0.2325	0.3190	0.4484

DELETED 00
13-41-01- LOGOUT
CONNECTED FOP 10 MINS
MILL TIME USED 17 SECS
SESSION COST 4.29

```
NOYCG AM     13:37        08/09/76

 THIS PROGRAM CALCULATFS THE CHROMATICITY COORDINATES AND
 PFRCFNTAGE TRANSMITTANCE / REFLECTANCE OF ANY SAMPLE FOR
         C.I.E. ILLU INANT C. USING THE 1931 DATA.


 INPUT VALUFS IN ORDER: RED, YELLOW, BLUE, DENSITY
 PUT COMMA BFTWEEN EACH VALUE. OBSERVE SIGN OF DENSITY.



                    SAMPLE  =  ? 420.

                    RED, YELLOW, BLUE, DENSITY  ? 3,24,0,.13

  COORDINATES IN ILLUMINANT C.

    X         Y             U        V          SAMPLE(%)

  .4732     .4763         .2437    .3678           37.09

                    *  *  *  *  *  *  *  *  *  *  *

                    SAMPLE  =  ? 417.

                    RED, YELLOW, BLUE, DENSITY  ? 4.4,27,0,.18

  COO DINATES IN ILLUMINANT C.

    X         Y             U        V          SAMPLE(%)

  .4941     .4649         .2604    .3675           27.45

                    *  *  *  *  *  *  *  *  *  *  *

                    SAMPLE  =  ? 416.

                    RED, YELLOW, BLUE, DENSITY  ? 18,50,0,.54

  COORDINATES IN ILLUMINANT C.

    X         Y             U        V          SAMPLE(%)

  .6034     .3903         .3727    .3616            3.32
```

```
               * * * * * * * * * * *

               SAMPLE  =  ? 450.

               RED, YELLOW, BLUE, DENSITY  ? 11,40,0,.54

COORDINATES IN ILLUMINANT C.

  X        Y           U        V         SAYPLE(%)

.5640    .4203       .3262    .3647          5.81

               * * * * * * * * * * *

               SAMPLE  =  ? 416.

               RED, YELLOW, BLUE, DENSITY  ? 26,50,0,.29

COO DINATES IN ILLUMINANT C.

  X        Y           U        V         SAMPLE(%)

.6298    .3670       .4101    .3584          3.97

               * * * * * * * * * * *

               SAMPLE  =  ? 429.

               RED, YELLOW, BLUE, DENSITY  ? 19,60,0,.37

COORDINATES IN ILLUMINANT C.

  X        Y           U        V         SAMPLE(%)

.6061    .3897       .3750    .3617          4.15

               * * * * * * * * * * *


USED     4.31 UNITS
```

BAUSCH & LOMB INCORPORATED

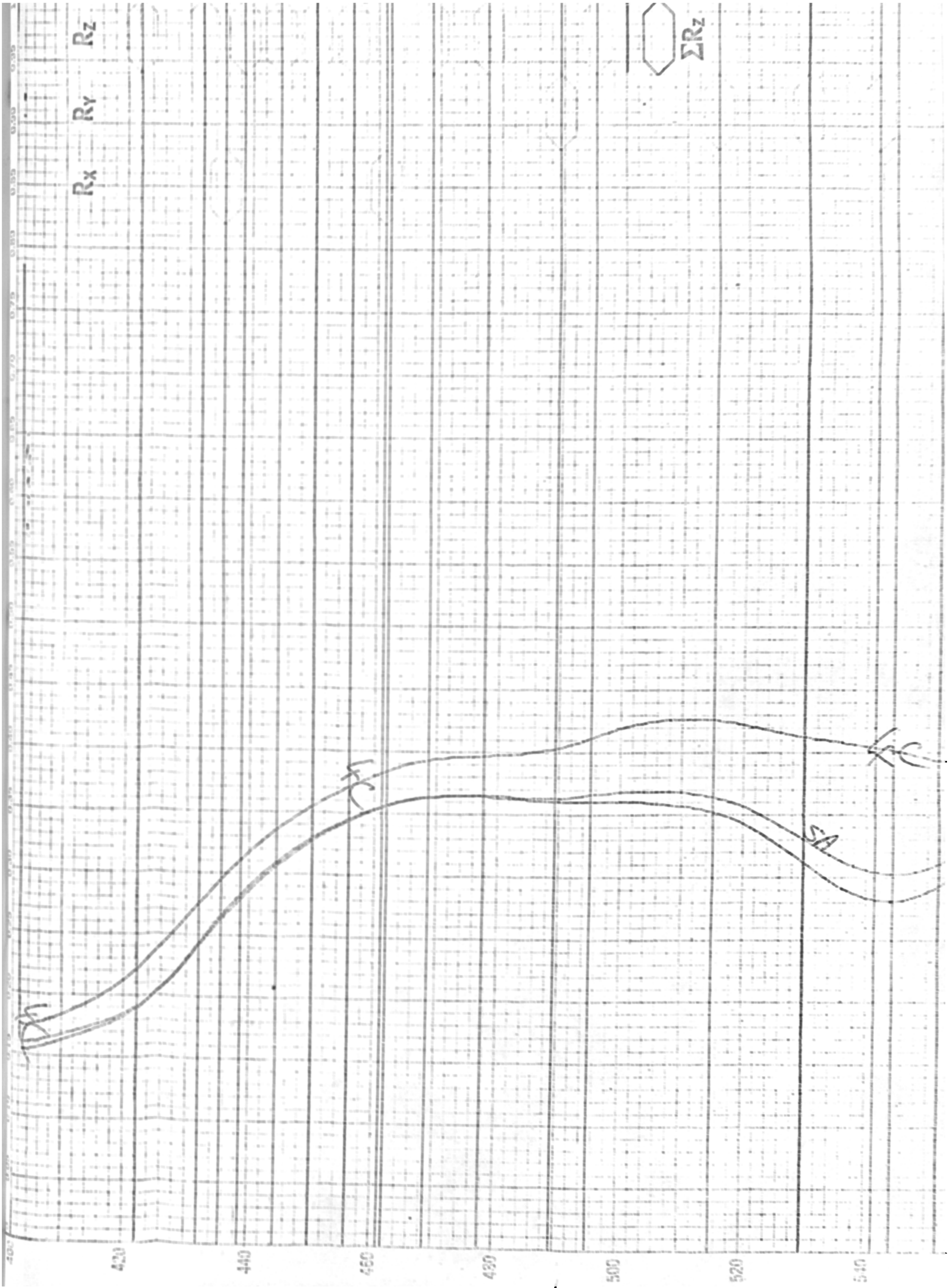


Figure 67 See page 203
Spectral reflectance curve - Luncheon meats.

BAUSCH & LOMB INCORPORATED

6f

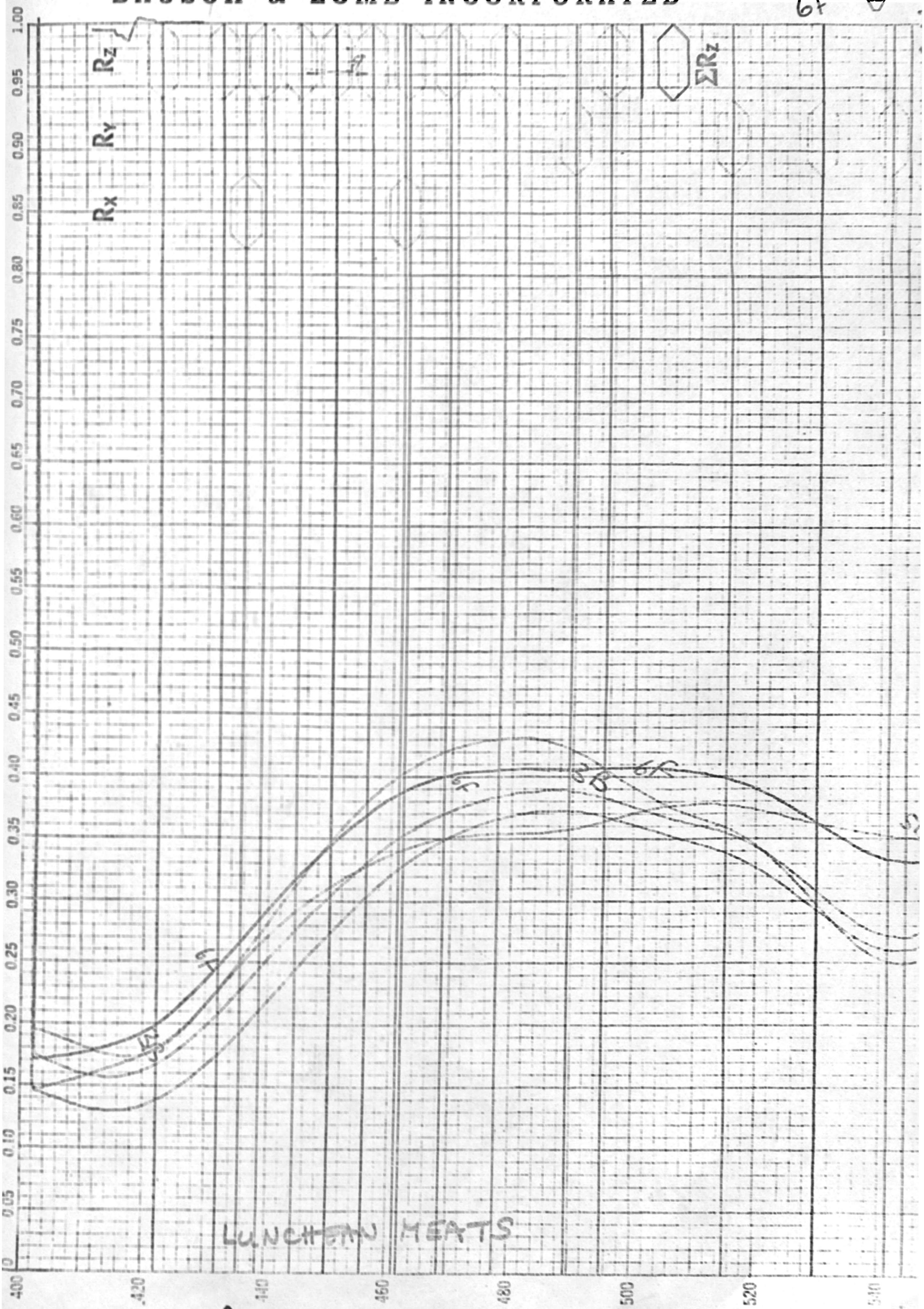
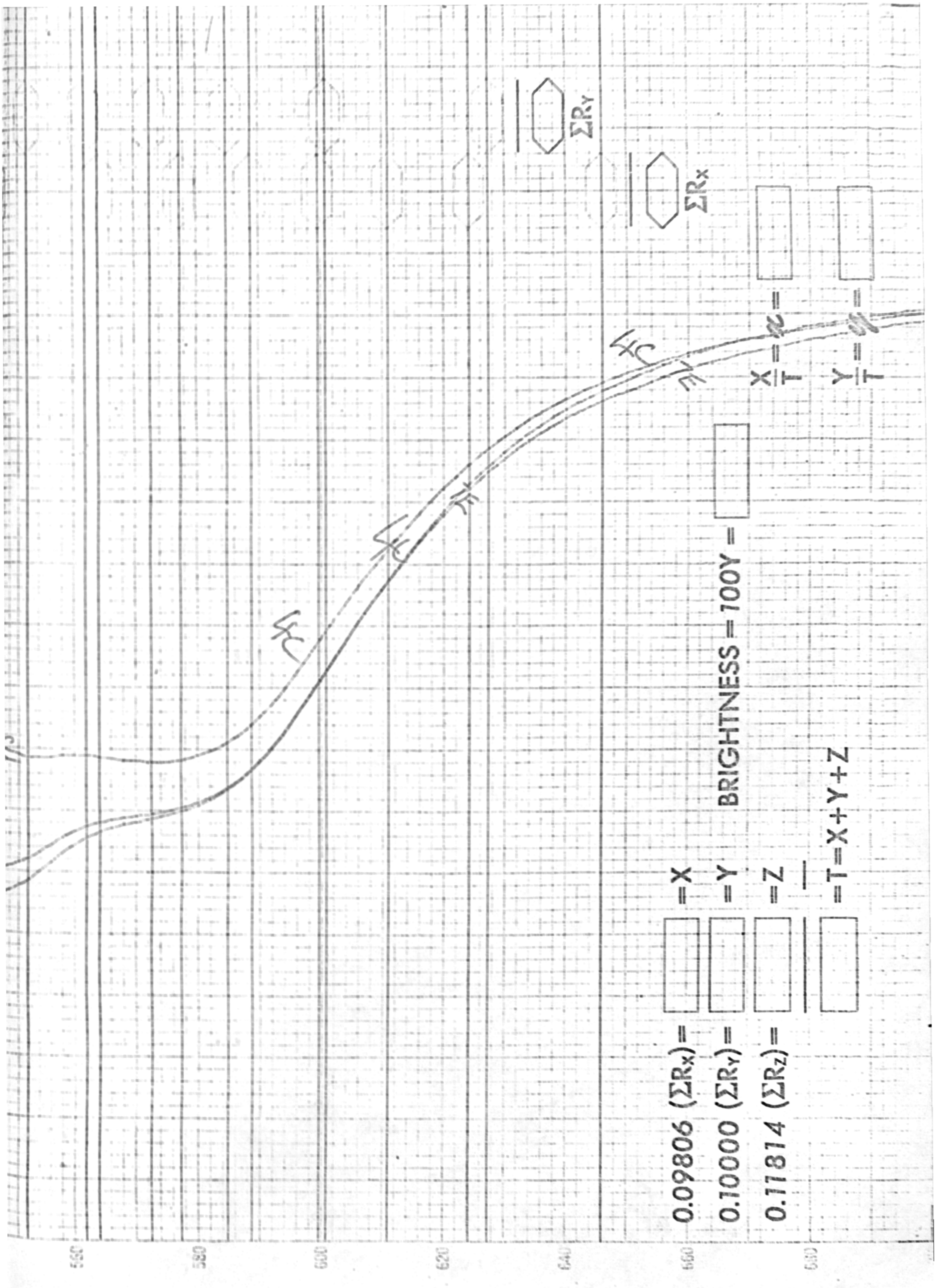


figure 67 See Page 203



CHROMATIC COEFFICIENT COMPUTING CHART FOR ILLUMINANT C
(SELECTED ORDINATE SYSTEM)

OPERATOR:
SAMPLE:
DATE:

CATALOG NO. 33 28-13